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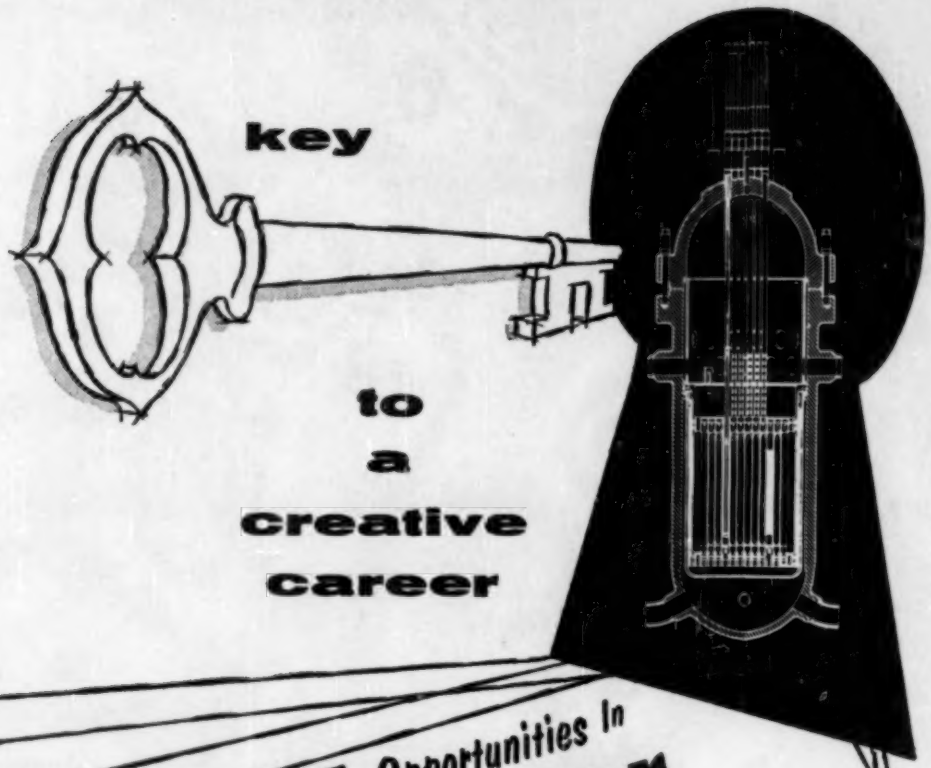

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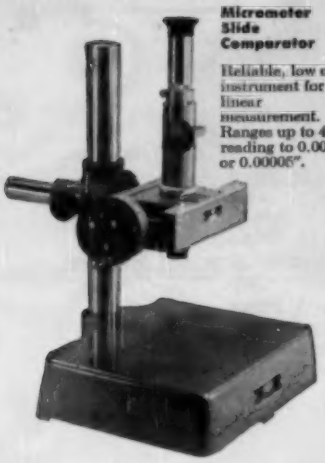

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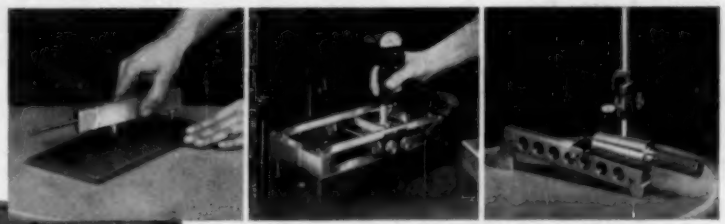

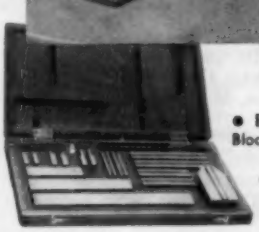

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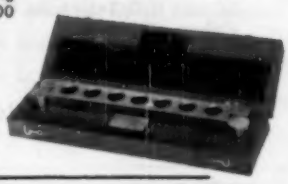

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The Nature of the Standard Control Chart, and Some of It's Competitors*

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Introduction

The standard control chart procedure, as proposed by Dr. Walter A. Shewhart,[1] has proven to be an effective tool for the improvement of the manufacturing process. It's record of success, however, does not protect it from competition with various other ways of using quantitative information for the same purpose. Therefore, quality control engineers and statisticians have not hesitated to suggest other methods which, for various reasons, they have judged to be preferable.

In preparing the present report no attempt has been made to prepare an exhaustive list of substitutes or to review critically the claims made for them. While a few alternatives will be outlined, the principal concern will be with a particular reason why it is logical to expect competition and with an objective basis for evaluating competitors.

The control chart is a tool used to guide decisions regarding an industrial process. The fact that there are other methods of using numerical data for this purpose is a sufficient reason why the control chart has competitors.

One way of comparing methods is to use several methods in attacking similar problems and then decide which one works best. This is not the basis of comparison to be considered here.

Another way to make comparisons is to set up a mathematical model for an industrial process, adopt definitions of control and lack of control, and then apply analytical procedures based on the theoretical foundation. This is the way which is followed in the present article.

A Statistical Model for an Industrial Process

Let us consider an observable quality characteristic of a product from an industrial process. Let us represent any numerical value of the quality characteristic at a specified time, t, by the random variable, $x(t)$. In advance of observation, we may expect that, at a specified time, $t = T$, $x(T)$ may have any one of a set of values $X_1, X_2, \ldots, X_n$. And to be very general, let us also assume that the range of possible values extends from minus infinity to plus infinity.

In order to provide for the possibility that some of these outcomes are more probable than others, let us assume a probability density function for x, denoted by $f(x)$, and such that

$$\text{Prob. } (x = X_i) = f(X_i) \qquad (i = 1, 2, \ldots n) \qquad (1)$$

or, when x is a continuous variable, such that

$$\text{Prob. } (X_i < x \leq X_j) = \int_{X_i}^{X_j} f(x)\, dx. \qquad (1')$$

As a first example, we consider a process producing individual units. The quality of an individual unit might be denoted by a zero, if acceptable, and by a one, if sub-standard. Then, if there is a probability, p', that a unit will be sub-standard, we have

$$\text{Prob. } (x = 0) = f(0) = 1 - p',$$
$$\text{Prob. } (x = 1) = f(1) = p'. \qquad (2)$$

As a second example, we consider that the length of the unit is to be measured and that the measurements have a normal distribution with an arithmetic mean, $\overline{X}'$, and a standard deviation, σ'_x. Then, for any pair of values, such as 0.416 and 0.428, we have

$$\text{Prob. } (0.416 < x \leq 0.428) = \int_{0.416}^{0.428} \frac{1}{\sigma'_x \sqrt{2\pi}} e^{-\frac{(x - \overline{X}')^2}{2(\sigma'_x)^2}} dx \qquad (2')$$

Let us consider, further, a sequence of random variables, $x_1, x_2, \ldots x_n$ where we now use x_i as a simplified notation for $x(T_i)$, $(i = 1, 2, \ldots, n)$. It is not too difficult to conceive of a process for which the density functions would change with time, that is, f_1 might be different than f_2 or f_3 [where, now, f_i is used as a short notation for $f_i(x_i)$]. The individual density functions might differ in type or they might be the same type, such as normal, but with different moments. To exemplify the latter situation, we display a possible correspondence, as follows:

$$\begin{array}{l} T_1, T_2, T_3, \ldots, T_n \\ x_1, x_2, x_3, \ldots, x_n \\ f_1, f_2, f_3, \ldots, f_n \\ \overline{X}'_1, \overline{X}'_2, \overline{X}'_3, \ldots, \overline{X}'_n \\ \sigma'_1, \sigma'_2, \sigma'_3, \ldots, \sigma'_n \end{array} \qquad (3)$$

In order to avoid misunderstanding it will be desirable to specify the particular time of reference whenever we study an industrial process. For instance we might refer to a process which has been turning out nails for the past eight hours or a process which is to extrude wire for the next ten minutes. If possible, we shall avoid such vague phrases as: "the steel-making process, the packaging process;" etc. Furthermore, we shall consider that a process turning out separate units has its time of operation measured in discrete steps, where each is the length of time between the completion of two consecutive units.

* Presented, by invitation of the Program Committee, at the Ninth Annual Convention, at New York, N. Y., May 25, 1955.
Prepared in connection with research sponsored by the Office of Ordnance Research, U. S. Army. It is released from copyright restrictions.

The Two Phases of Control

The Shewhart control chart is used for two phases of control. The first phase is described [2] as "control when no standard is given" and the second as "control with respect to a given standard." These phases correspond to the two uses [[3], p. 39] "for analyzing past inspection data for control" and "for controlling quality during production."

In the first phase, data are collected more or less in the order of production and then two questions are posed:

(1) Is the process in control?

(2) Is the process satisfactory?

The first question might be stated more precisely as

(1′) Has the process been in control for all of that time-period, T_p, during which the product that furnished the data was being made?

The second question could be restated as follows:

(2′) Does a sufficiently high proportion of the product made during T_p meet specifications?

Neither the original questions nor the rephrasings reveal the matters at stake. As usual, we have failed to make clear our real reason for collecting data. As usual, we propose to make inference regarding the future on the basis of study of the past. What we really want to know is

(2″) Will this process produce satisfactory product *in the future?*

If it is true that the process has been in control and has produced satisfactory product in the past, we are willing to assume that it will produce satisfactory product in the future. This assumption may or may not contain the implied proviso, "if conditions remain the same."

In the second phase of control, "control with respect to a given standard," data are collected from time to time, in order to answer the apparent question:

"Is the process in control with respect to the standard given?"

As a question regarding the specific instant when the sample was taken, the inquiry is rather trivial. If the query is directed toward a time interval during which a number of uninspected units have been produced it becomes important. It is difficult to guess just what interval an individual has in mind when he asks the question.

For the present it seems useful to rephase the question, tentatively, as follows:

"Has the process been in control with respect to the given standard during the time interval, T_s?"

In this connection it might be noted that, in advance of data collection, we expect to decide what the size of the time interval is to be and then plan our experiment accordingly. For example, we may decide that, during the day, we will collect eight samples of five units each, so that, at the end of eight hours, we can hazard an answer to the question:

"Has the process been in control during the past eight hours?"

Returning to the first phase, we shall define control in the strict sense when no standard is given, as follows:

A process is in control in the strict sense during the time, T_p, when

(1) $f(x)$ is identical for every $x(t)$, with t in the interval T_p, and

(2) the set of random variables $[x(t)]$ are statistically independent.

As an example, our nail producing process would be said to be in control today if, for each nail, the probability, p', of it being defective is identical, and if the probability for the joint state of any group of nails is equal to the product of the probabilities of the component states of its members.

As a counter-example, our extrusion process would not be in control today if, at any two times, T_1 and T_2, $f(x_1) \neq f(x_2)$.

For the second phase, "control with respect to a given standard," we assume that the standard is given as a density function, $f^*(x)$, and state:

A process is in control in the strict sense with respect to a standard, $f^*(x)$, during the interval T_s, when

(1) $f(x)$ is equal to $f^*(x)$ for every $x(t)$ with t in the interval, T_s, and

(2) the set of random variables $[x(t)]$ are statistically independent.

As an example of a process which could be in statistical control but not in control with respect to a given standard, consider our nail-producing process today if, for every nail, p' is 0.10 but the standard is 0.05.

Competitors of the Control Chart Procedure for Defectives in Phase I

Clearly, the questions which these control chart procedures are supposed to answer are quite similar to the questions which might be answered by using other statistical procedures. It will be noted, however, that certain differences in the use of the end-product exist.

Let us extend the nail example slightly by assuming that nails are produced at the uniform rate of 60 per min for an 8-hr period. Suppose we wish to test the hypothesis of control in the strict sense. We can arrange to take 20 nails at each of ten periods and count the number of defective nails in each sample. Let us denote the potential results by $c_1, c_2, \ldots, c_{10}$.

According to definition the hypothesis of control in this case is equivalent to the hypothesis that p' is, independently, the same for each and every nail. If such is the case, then, *for each of the ten periods when the samples are taken*, p' will be the same. Obviously, the converse does not necessarily hold but the assumption that it does may appear to be reasonably plausible.

The control-chart test procedure is well known. We calculate

$$\begin{aligned} \text{UCL} &= 20\bar{p} + 3\sqrt{20\bar{p}(1-\bar{p})} \\ \text{LCL} &= 20\bar{p} - 3\sqrt{20\bar{p}(1-\bar{p})} \end{aligned} \qquad (4)$$

where $\bar{p} = \dfrac{\sum_{i=1}^{10} c_i}{200}$

We agree to reject the hypothesis that p' is the same for all nails if one or more of the c-values exceed UCL or are less than LCL.

For convenience let us write

$$\chi_i^2 = \frac{(c_i - 20\bar{p})^2}{20\bar{p}\bar{q}} \qquad (5)$$

Then it is easy to verify that the above test is equivalent to the following: Reject the hypothesis that p' is the same for all nails if one or more of the χ_i^2-values is greater than nine.

A competitor for this test is the ordinary χ^2-test: Reject the hypothesis that p' is the same for all ten periods if $\sum_{i=1}^{10} \chi_i^2$ is greater than 16.9.

For the latter test, the probability that the hypothesis under test will be rejected when it is true is approximately five percent. It is well known [(4) p. 218] that the approximation stems from the assumption that the c-values are normally distributed.

An approximation of unknown accuracy can be obtained for the corresponding type I error of the control-chart test by using results from a recent paper by Halperin and associates.(5) Tables 1 and 2, in this paper, give upper and lower limits for five percent and one percent points, respectively, for the distribution of d, where

$$d = \max_{i = 1, 2, \ldots, k} \frac{|x_i - \bar{x}|}{s} \qquad (6)$$

The x_i are independent variables with the same normal distribution. The quantity, $\bar{x}$ is the arithmetic mean of the k x-values. The quantity s is an independent* estimate of the universe standard deviation, based on m degrees of freedom. If we conjecture that

$$\max_{i = 1, 2, \ldots, 10} \frac{|c_i - 20\bar{p}|}{\sqrt{20\bar{p}\bar{q}}} = d \text{ with } m = \infty \qquad (7)$$

then the one percent point is 3.12 and the five percent point is 2.65-2.66. This suggests that the corresponding value, 3, used in the formulas in (4) may give a type I error of about the same magnitude. Some work of E. P. King (6, 7) points in the same direction. Actual computations for p' at 0.05 and 0.10 give 6.0 percent and 3.5 percent respectively.

While the two tests seem roughly comparable in so far as their respective probabilities of rejecting the hypothesis of control when control exists, their power against certain alternatives may be quite different. This can be expected since the control chart tests for outliers directly while the χ^2 test measures the joint deviation of all the sample means from their centroid.

It has been emphasized (1) that the control chart "provides a basis for action." If a point falls outside the control band (i.e. if the test rejects the hypothesis of control) then the assignable cause should be "found and eliminated." If the point is above the upper control limit then it is obvious to suspect that p' was higher at that time than at most of the other times when the samples were taken.

An investigation of the power of the control chart for number of defectives is being made. While it is very incomplete, there are a few results available which apply to the present example. Let us suppose that p' is at p_1' when nine of the samples of 20 are taken but is at p_2' for the tenth sample. In Table I we have for each of four combinations of p_1' and p_2', the approximate probability, that the tenth sample point will be above the upper control limit. (This table gives the approximate probability that the number of defectives in the sample of 20, taken when p_2' is in effect, will be greater than the upper control limit based on this sample in combination with nine other samples of 20, taken when p_1' is in effect.)

It is worth noting that the control chart is not unique in indicating where to look for trouble. If we run a χ^2-test and find significance, we are inclined to single out the sample value making the largest contribution and to look for trouble at that point.* This matter is illustrated by the sampling results given below. The tenth sample of 20 gives a correct indication of the time of lack of control when the usual control-chart procedure is used. Also the χ^2-test indicates lack of control and, when the largest contributor is sought for, we find it to be the tenth sample.

Table II gives the numbers of defectives in nine samples of 20, taken from a population with a fraction defective of 0.05 and for a tenth sample of 20 from a population with a fraction defective of 0.50.

The Control Chart for Means in Phase I

Turning, now, to the Control Chart for $\bar{X}$, we find that the analysis of variance is the usual competitor. For the time period T_p, we post the question,

"Has the probability density, f, been constant?"

If we are willing to assume that the densities have been the same, with the possible exception of different values for the means, then we may use the test procedure: Reject the hypothesis that $\bar{X}'(t)$ is constant for all t in T_p, if for any sample, $\bar{X}$ is greater than $\bar{\bar{X}} + A_2\bar{R}$ or less than $\bar{\bar{X}} - A_2\bar{R}$.‡

Considerable work by E. P. King (6, 7) supports the wisdom of using 20 to 25 samples and there are good arguments for using samples of about five units each.

King's analysis of the behavior of the "chart for averages" is based on the assumption of normality. On this basis he found (6) that, for a test based on 20 groups of five units, the probability of rejecting the hypothesis of control when true is between three percent and six percent. Experimental work by King, as reported in a later paper (7) indicates that the value is slightly below five percent.

Obviously this test for control can be written in the form: Reject the hypothesis of control if d^* is greater than three, where

$$d_i^* = \frac{|\bar{X}_i - \bar{\bar{X}}|}{\bar{R}/(d_2\sqrt{n})} \text{ and } d^* = \max_{i = 1, 2, \ldots, k} d_i^* \qquad (8)$$

(k is the number of samples, n is the sample size, d_2 is the expected value of $\bar{R}/\sigma'$).

* This condition would be satisfied if we used another random sample of m + 1 values and calculated s from

$$s^2 = \sum (x_j - \bar{x})^2/m \qquad (j = 1, 2, \ldots, m + 1),$$

where $\bar{x}$ here is the mean of this new sample.

* At this stage in the preparation of this article, the author's attention was called to a paper by Henry Scheffé,* which, unfortunately had been overlooked. It is difficult to estimate how much some of the thoughts in this article have been influenced by a past reading of Scheffé's paper.

‡ The matter of a test for equality of variances has not been overlooked but will be considered in a later report by E. G. Olds and R. W. Kennard.

TABLE I

P'_2	P'_1 0.05	0.10
0.50	0.99	0.90
0.25	0.53	0.18

TABLE II

Sample No.	c_i	χ_i^2	
1	1	0.315	Upper control limit for np: 5.441.
2	0	1.858	
3	1	0.315	$\chi^2_{0.05} = 30.144$. (for 9 d.f.).
4	1	0.315	
5	0	1.858	
6	1	0.315	
7	0	1.858	
8	2	0.058	
9	3	1.087	
10	8	25.521	
	17	33.500	

If, as the denominator of d_i^*, we use the Fisherian estimate* of the standard deviation of $\overline{X}_i$ instead of an unbiased estimate based on range, then we have the studentized maximum absolute deviate displayed in (6). With s calculated by use of the internal deviations in the 20 samples of five the degrees of freedom for entering the tables of Halperin and associates [5] would be 80. Then the bounds for the five percent and one percent significance levels would be about 3.03 - 3.06 and 3.55 - 3.56, respectively. For a direct comparison of d and d^* we should adjust for the loss in efficiency in using R. With the effective degrees of freedom reduced to about 73, the bounds for the five percent and one percent points are 3.04 - 3.07 and 3.57 - 3.58. Therefore the value of 3 would seem to correspond to a point slightly above five percent, which agrees quite well with King's findings.

As suggested above, an alternative to the control-chart test is an analysis of variance based on $\Sigma(d_i)^2$, $\Sigma(d_i^*)^2$, or on studentized range. (See Craig's paper [6] for a comparison of control charts and the usual analysis of variance.) In practice, the rejection of the null hypothesis will be followed by a study of the components making the larger contributions to the rejection. This leads to the tantalizing problem of multiple comparisons, including the interpretation of observed slippages and gaps.

If, after analyzing past data by use of appropriate chart, or charts, the hypothesis of control is accepted we meet question (2"), as posed above,

"Will this process produce satisfactory product *in the future?*"

Consideration of the statistical approach to this far-reaching problem will not be attempted here but it might be noted that the problem is not peculiar to the control-chart setting.

Control With Respect to a Given Standard for a Specified Interval

The decision as to whether or not an industrial process is in control with respect to a given standard, f^*, for the period T_s, can be based on the result of testing the hypothesis that $f(x)$ is equal to $f^*(x)$ for all $x(t)$ with t in T_s, where $f^*(x)$ is the standard given. Assuming that x is continuous, we may use the following control-chart procedure as a test:

(a) Calculate the arithmetic mean $\overline{X}^*$, and the standard deviation, σ^*, for $f^*(x)$.

* Calculate the sum of squares of deviations within each sample, get the total, divide by $k(n-1)$, and extract the square root.

(b) Calculate control limits for $\overline{X}$ and R for controlling quality during production. (Use formulas given in *A.S.T.M. Manual*,[2] *A.S.A. Standard Z1.3*,[3] or in one of the standard texts on statistical quality control).

(c) Plan to take samples of n units at each of k times during the interval T_s, and to calculate $\overline{X}$ and R for each.

(d) If any $\overline{X}_i$ or R_i ($i = 1, 2, \ldots k$) are outside their respective control limits, reject the hypothesis that the process is in control with respect to the given standard for the period T_s.

Let us consider a concrete example of a process which is to run for an eight-hour day and suppose that, during the day we arrange to take ten samples of five units each. Further, let f^* be a normal density function. Then it can be easily verified that the probability that both $\overline{X}_i$ and R_i will be within the control limits will be 0.9924 when f_i is equal to f^*. Therefore, an individual sample will be rated as a defective with probability 0.0046. Further, the probability that at least one out of the ten samples will be rated as a defective is found to be about 0.073.

Consider, now, the single-sampling plan: $n = 10$, $c = 0$. What we have done above is to schedule the use of such a plan for a situation for which the Acceptable Quality Level is 0.46 percent. Further we have found that the Producer's Risk at the Acceptable Quality Level is about 7.3 percent.

The procedure which we have outlined differs from the standard procedure, which specifies that a single sample be taken and that the hypothesis of control is to be rejected if either the sample mean or the sample range are outside their respective control limits. There is no criticism of the standard procedure as a test of the hypothesis of control at the time the sample is taken. If the test is repeated at times T_2, T_3 . . . , however, it is almost inevitable than the hypothesis of control will be rejected sooner or later for a controlled process. While the expected number of trials for rejection is about 217, obviously rejection may occur much sooner.

When the hypothesis of control with respect to the given standard is rejected, a search for the assignable cause is supposed to be made. It is not uncommon for this search to extend back over the time during which several samples were taken. Thus, if an indication of lack of control is found at T_k, the search may move from T_k to T_{k-1} to T_{k-2}, and finally, perhaps, to T_{k-n}. If suspicion of the process for the period from T_{k-n} to T_k is entertained then the implication is that the hypothesis of control was not, in fact, accepted for that interval. If such is the case then it seems that, when the hypothesis of control is true, the probability for its acceptance is zero.

The above difficulty can be eliminated by specifying in advance the time interval for which the decision is to be made. Then, if a given number of samples are contemplated, it is possible to calculate the probability of accepting the hypothesis of control when it is true and also to calculate the power of the test for rejecting alternatives.

For the example just considered, suppose that only the control procedure for means is used. Then our procedure is equivalent to the single-sampling plan; $n = 10$, $c = 0$; with an Acceptable Quality Level of 0.27 percent and a Producer's Risk of 2.66 percent at the acceptable quality level.

TABLE III—Probability of Rejecting The Hypothesis of Control With Respect To a Given Standard When the Process Mean Shifts one σ Above the Standard Between the Times that the r-th and (r+1)st Samples of Five Units are Taken.

r	$1-\beta$	r	$1-\beta$
0	0.9192		
1	0.8963	6	0.6403
2	0.8670	7	0.5386
3	0.8295	8	0.4082
4	0.7813	9	0.2410
5	0.7195	10	0.0266

Now suppose, as an alternative, the process mean increases by an amount, σ', and that the shift occurs between the time that the rth and the $(r + 1)$st sample is taken, and is in effect for the rest of the samples. The power of the test is given in Table III for the possible values of r. Figure 1 shows these data graphically.

Obviously the power of this test for other types of alternatives such as linear trends, could be calculated. Furthermore, the behavior of the complete test, with both averages and ranges used, could be studied. Perhaps the example given is sufficient, however, to illustrate the point that the proposed definition of control with respect to a given standard for a specified interval permits the adoption of a planned testing procedure with known characteristics.

In addition to the standard control-chart procedure or the alternative proposed, there are, of course, various well-known statistical procedures for collecting and utilizing data to test the hypothesis that a density function has a given mean and variance for a specified time period. Clearly, some of these competitors can be expected to be more powerful against types of alternatives. However, it seems probable that only those competitors which depend on stratified or systematic sampling will be effective for the usual alternatives to control. It is planned to investigate this matter more thoroughly.

One further remark might be added here. While the process may not be in control with respect to the standard given, it may be in control with respect to some other standard. Therefore, one might test first for control with respect to the standard given, and then, if this hypothesis is rejected, test for control where no standard is given, as in phase one.

This multiple decision procedure seems to have interesting possibilities. It bears some resemblance to that followed by a manufacturer who inspects a lot first in order to decide whether it meets the standards of a particular customer, and then, if the decision is negative, he decides whether the lot will be saleable at all or should be scrapped.

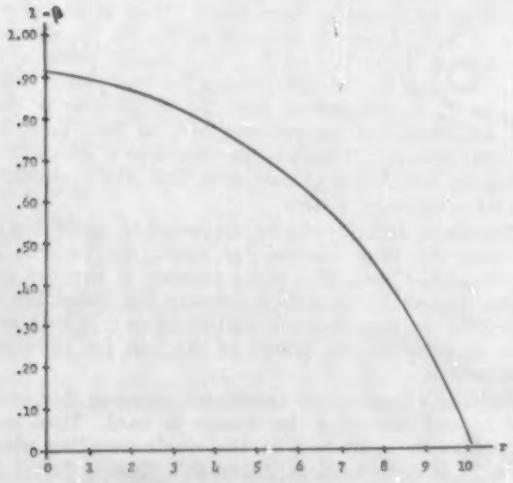

Figure 1—Power Curve Based on Information in Table III. (It can be verified that the graph of log β versus r should be a straight line.)

Summary

Using a statistical model for an industrial process, we have defined control in the strict sense for a specified time interval. We have noted that, because of the essential unity of statistical methods, it is not surprising to find competitors to the control chart. Since recent work makes comparative analysis possible, some precise results have been reported for competitors in the situation where the standards for control are not given. When control with respect to a given standard is defined, the convenience of specifying an interval has been illustrated and the probable nature of close competitors has been suggested.

Not stated, but implied, in the body of the article, is this general thesis: Some appreciation of statistical principles is almost a necessity in order to gain a deep understanding of the nature of the control chart. Furthermore, this appreciation will help to restrict the list of competitors to those having sound theoretical grounds for consideration.

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Quality Control As Applied to Continuous Processes

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Introduction

This article will be limited to discussion of continuous processes in the manufacture of steel wire. It would be wise to define what is meant by the term "continuous processes" as applied in this instance. The dictionary states that the adjective "continuous" means (1) "having the parts in immediate connection; (2) uninterrupted in time; without cessation." These definitions don't actually tell us much. Therefore, in order to avoid a battle of words, we shall illustrate by designating specific operations as continuous.

It will be helpful to consider a thumbnail sketch of the operations involved in the manufacture of steel wire in an integrated plant. The basic raw materials are coal, iron ore, limestone, and air. Other metallic elements are introduced in the steel-making phase as shown in the simplified flow chart in Fig. 1.

This is really a streamlined version of the process but it will help those who are not familiar with the details to orient the specific processes we intend to designate as continuous. These are: the "continuous" type heat treating processes, the wire drawing processes, and the metallic coating process. We will limit our discussion to the first two of these.

Objectives

What do we hope to accomplish by quality control of such processes? Certainly we must have an objective and the quality control objective must be consistent with the objectives of the whole enterprise. The basic objective of any industrial enterprise in a free economy is to make a fair and equitable profit for the investors therein, namely, the stockholders. In order to accomplish this, the enterprise must produce a product for which a purchaser is willing to pay more than the cost to make and deliver it. For a purchaser to be willing to pay for a product, it must possess functional and/or esthetic value or quality. The objective of quality control is the regulation of quality at such a level as to maintain the purchasers' desire to buy the product as well as regulation of quality at such a level as to permit the manufacture of the product at a cost which will permit attaining the primary or profit objective. This must be accomplished in the face of stiff competition from other similarly employed enterprises.

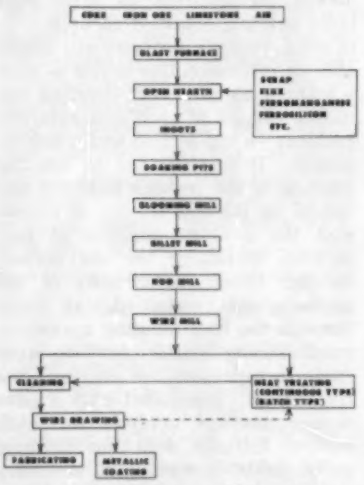

Figure 1—Simplified Flow Chart of Processes Involved in Manufacture of Wire.

In the manufacture of as complex a product as steel wire, as in the case of many other products which we are so likely to take for granted, the control of quality at any stage of the manufacturing process must be integrated with the quality requirements of the end product. This is usually accomplished by setting standards of performance or of characteristics for each of the various operations or processes involved. Although we will be discussing what are seemingly isolated operations we must not lose sight of the overall quality requirements.

Continuous Heat Treating Processes

Continuous heat treating processes are characterized as such because the steel rod or wire which is to be subjected to the operation actually moves through the heat treating media in a continuous manner as opposed to remaining stationary. Equipment is built to accommodate multiple rods or wires moving in parallel through the heat treating cycle. The purpose of such treatment is to modify the microstructure of the steel in such a manner as to improve its cold working characteristics, its strength, and its toughness. The variables to be considered are time, temperature, heating capacity, analysis, and size of the steel to be heat treated. Time is a function of the length of the heat treating media and the speed with which the steel moves. The former is controlled by the design of the equipment and is a limiting factor rather than a variable. The analysis and the size of the steel are two significant variables which are dictated by product specification requirements. For the types of heat treatment we have in mind, the analysis may vary from 0.20 percent carbon up to 0.90 percent carbon, while the size may vary in 0.001 inch increments, from 0.020 inch diameter to 0.500 inches.

Time of heat treatment is predicated on metallurgical considerations and once established, is varied only with size of the steel rod or wire and with certain broad analysis groupings. The temperature level is also predicated on metallurgical considerations and may be varied moderately on the basis of broad analysis groups. In commercial practice these so-called operating variables are established at as near optimum levels as possible and maintained as nearly constant as possible in order to achieve efficient operation and uniform quality. The product variables —analysis and size—must of necessity vary with end-product specifications. Hence the problem is one of establishing a convenient and economical method of quality control insofar as these two variables are concerned. A direct criterion for control could be founded on the examination of the micro-structures obtained. Determination of microstructure, however, is a time-consuming and costly operation. An indirect criterion, involving the me-

TABLE I—Tensile Strength and Steel Analysis Data for Correlation Study

X_0 Tensile 10^3 p.s.i.	X_1 Carbon $\times 100$ Percent	X_2 Manganese $\times 100$ Percent	X_3 Phos. $\times 100$ Percent	X_4 Silicon $\times 100$ Percent
150.3	65	91	2.0	23
145.0	65	91	2.0	23
134.3	58	88	2.0	19
136.5	58	88	2.0	19
151.8	63	90	2.2	22
114.2	41	100	2.2	21
110 5	41	100	2.2	21
142.8	69	100	1.0	25
146.3	69	100	1.0	25
109.5	46	69	1.3	20
105.0	46	69	1.3	20
127.7	53	90	1.6	24
143.1	66	83	1.4	15
137.4	66	83	1.4	15
137.8	65	87	1.9	22
138.2	65	87	1.9	22
135.5	63	70	2.2	24
135.9	63	70	2.2	24
131.4	62	80	1.6	24
134.9	52	89	2.5	21
142.8	63	95	2.2	27
150.5	65	91	2.0	21
148.0	65	91	2.0	21
123.9	58	81	1.2	22
128.6	51	93	1.5	23
103.3	40	93	1.6	23
101.6	40	93	1.8	23
105.1	41	88	2.0	27
105.5	41	88	2.0	27
139.9	64	88	2.0	25
133.2	64	88	2.0	25
149.1	61	88	1.8	22
144.6	61	88	1.8	22
134.8	54	93	1.6	24

(Data in Columns X_1, X_2, X_3, and X_4 coded by multiplying original by 100. Data in Column X_0 have not been coded.)

chanical properties of the steel, is more practical and more manageable from the standpoint that numerical indices are readily obtained. Therefore, control of the process is set up on the tensile strength and in some instances, also on the reduction of area which occurs at the tensile "break".

The problem seems to be quite simple. All we need do is collect enough data and we can set up $\bar{X}$ and R charts. But how should we collect these data? We already know from our metallurgical experience that analysis has a marked effect on tensile strength. And what about size? If one is unwilling to accept the metallurgist's answers, a properly designed experiment with subsequent analysis of variance will provide the answers. In this instance, being metallurgists we accepted our own answers. A rational grouping of data, therefore, might be by recognized grades of steel and by, perhaps, broad size groupings. If this heat treating operation were an isolated process with the product therefrom an end product such grouping might be adequate. Since, normally, it is only one of a number of steps of an integrated process, other considerations or refinements might be more significant.

One such refinement could be brought about by a more accurate evaluation of the relationship between the analysis of the steel and the tensile strength resulting after subjecting the steel to the specific heat treatment involved. Fortunately, this can be done by means of a multiple correlation study. Data for any statistical study must be scrutinized for accuracy and availability. If the problem is one of purely academic interest, we need not be concerned about the future availability of comparable data. Our problem, however, is to establish a means for future control of an industrial process, hence, we must make sure similar data will be or can be made available in the future. The point is that whereas we could obtain data from an adequate number of samples of steel of different analyses, by analyzing each one, heat treating each one, and then testing each one, similar data for future control purposes would not be economical. Therefore, it behooves us to determine what data are available and then to determine whether they can be used. In this particular instance, in addition to the usual ladle analysis obtained on each heat of steel, recheck analyses are available on representative billets in such a manner as to permit dividing the usable portion of each heat into two portions—a top section and a bottom section. It was decided to use the average of the recheck analyses obtained on the top section to represent the average analysis of that section. Similarly for the bottom section. Since the identity of the sections was retained, at least through the heat treating operation, tensile strength determinations were made to represent the average tensile strength associated with a particular average analysis for each section. Initially, data thus obtained on 50 heats of steel (100 sections) were used for a multiple correlation analysis with tensile strength as the

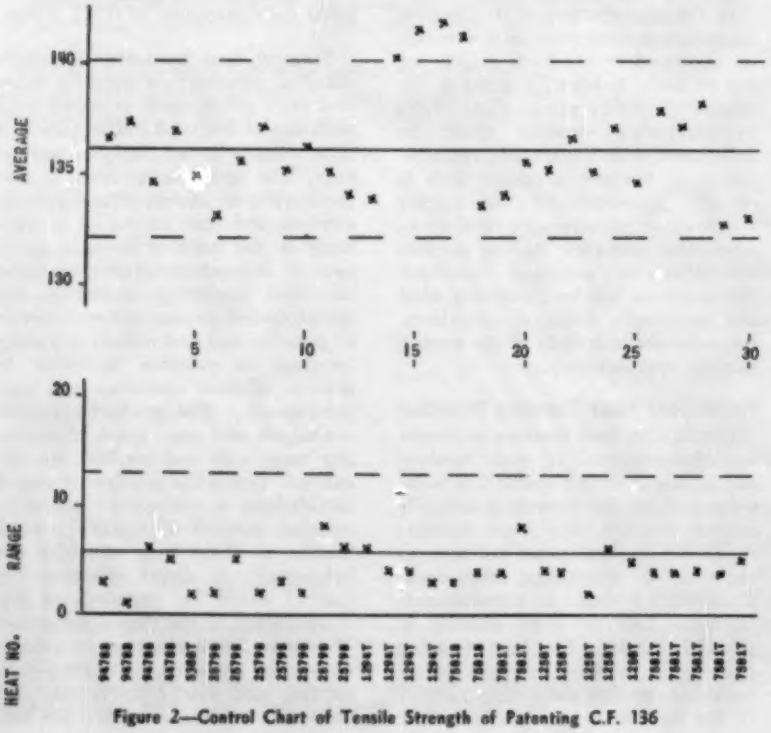

Figure 2—Control Chart of Tensile Strength of Patenting C.F. 136

dependent variable and carbon, manganese, phosphorus, and silicon content as the independent variables. Subsequently, data from 100, 200, and 300 heats were subjected to multiple correlation analysis with a slight improvement in the coefficient of correlation and the standard error of estimate.

In this instance, the multiple correlation study confirmed the expected nature of the relationship between the variables. In addition it provided a quantitative measurement of the individual influences which when expressed in the form of an equation could be used to predict, on the basis of known average analysis, the average tensile strength to be expected of a new heat of steel when subjected to the same heat treatment. A measure of the security of such a prediction can be provided by computation of the standard error of estimate. It should be noted that the prediction equation is of questionable value beyond the limits of the variables included in the study.

The prediction equation fits into the scheme of control by virtue of the fact that through its proper use we can "catalogue" steel with respect to a significant property, namely, tensile strength. Then, upon heat treating the steel we can determine whether it is conforming to the expected. Failure to conform would indicate either lack of control of the heat treating process or something unusual about the steel. Initially, the criterion of conformance was whether the actual average tensile was within plus or minus two standard errors of the computed tensile. If such were the case, that particular lot was passed on to subsequent operations for processing as originally designed. If the lot did not conform, action to re-catalogue or re-work the lot was initiated. Control charts for average tensile strength were set up with control limits equal to two standard errors as obtained in the correlation study. Eventually, as accumulated data indicated that the variability within subgroups was reasonably constant over the range of different analyses, control limits were set at $A_2\overline{R}$. This was done on the premise that the cataloguing by means of the prediction equation would segregate the steel into specific populations. The introduction of the range chart strengthened the control over the product.

TABLE II—Summary of Multiple Correlation Study

Prediction equation:
$X'_0 = 17.6 + 1.48\ X_1 + 0.22\ X_2 + 4.88\ X_3 + 0.06\ X_4$
Coefficient of Correlation, $r_{0\cdot1234} = 0.95$
Coefficient of Determination, $r^2 = 0.90$
Standard Error of Estimate, $S_{e\cdot1234} = 4.51$

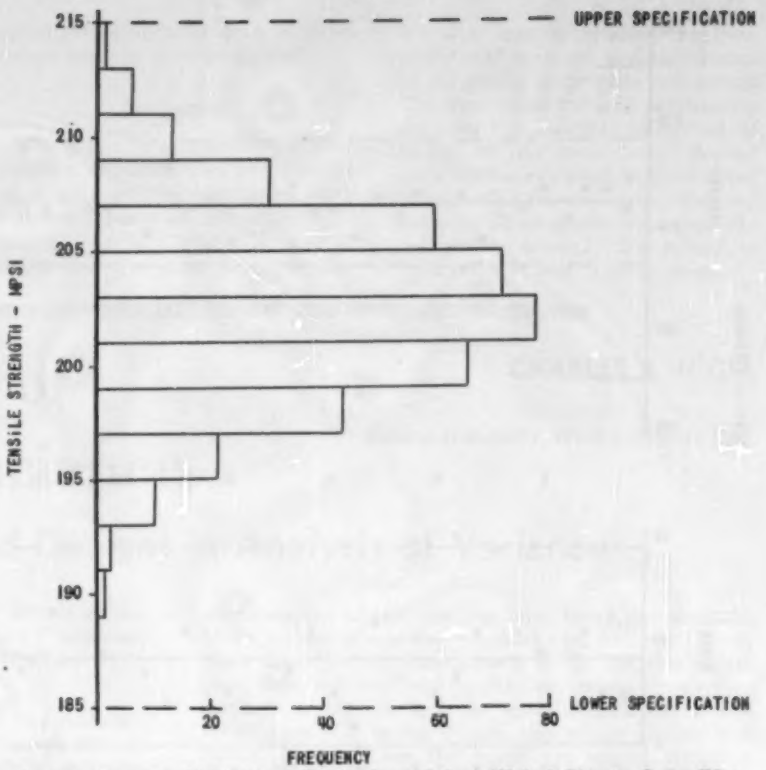

Figure 3—Frequency Distribution of Tensile Strength for 0.148 Inch Diameter Spring Wire
Average = 202,000 p.s.i.
Standard Deviation = 4,030 p.s.i.

Table I shows a portion of the original data in partially coded form. Table II presents the results of the multiple correlation, namely, the prediction equation, the coefficient of correlation, and the standard error of estimate, and Fig. 2 illustrates a typical control chart.

Wire Drawing

The problem of establishing quality control by statistical methods in the wire drawing operation is complicated primarily by the variety of specifications to which wire is manufactured. The quality characteristics of major concern usually are size and mechanical properties. The size, or diameter, is determined by the selection of proper dies, and since the advent of tungsten carbide wire-drawing dies, has not been much of a problem. Mechanical properties, however, result from the combination of three variables: analysis of steel, heat treatment, and cold work, that is, the operation of wire drawing itself.

The general control problem is one of maintaining the proper relationship of these three variables in order to assure that lot after lot of material processed will attain the desired mechanical properties. The specific control problem is one of verification that the desired characteristics have been attained. This, naturally, is done by testing and inspecting the final product. For our example we will discuss tensile strength, the most common mechanical property specified. It is readily determined by a simple, though destructive, test. Data are easily accumulated. As you might expect, these data show variability and can be subjected to the various means of analysis such as frequency distributions, computation of averages and standard deviations, and, naturally, plotting of $\overline{X}$ and R charts. In theory, therefore, it is relatively simple to set up control.

The actual mechanics of such a verification or control system is complicated, as mentioned earlier, by the variety of specifications or products normally manufactured in a wire mill. In addition, sampling, which is essentially of the stratified type, is a matter of concern. Obviously only the ends of a coil of wire can be subjected to a destructive test. Another difficulty lies in the fact that lot sizes are compartively small.

No single solution can be advanced for the problem of multiplicity of products. At least at the outset of a

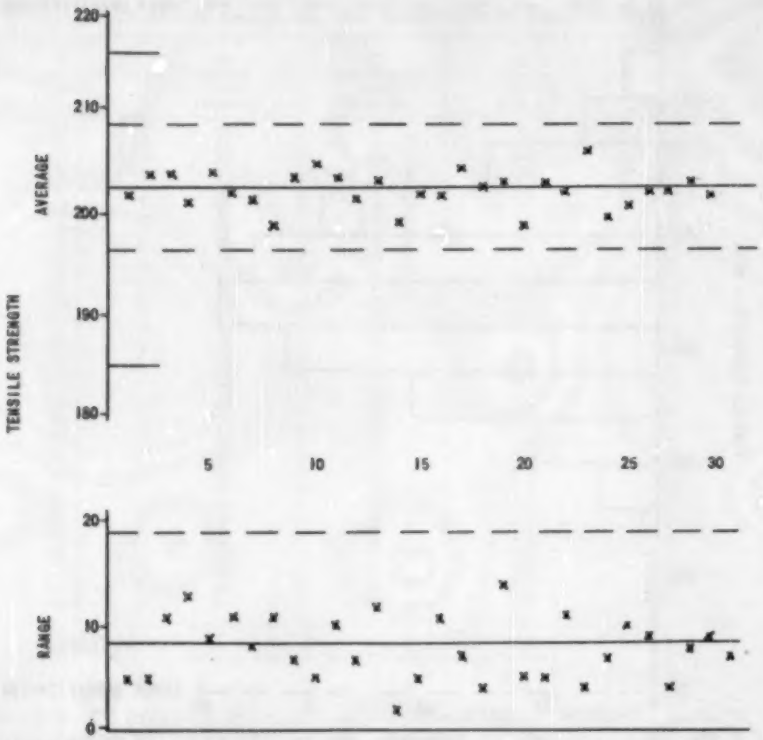

Figure 4—Control Chart of Tensile Strength for 0.148 Inch Diameter Spring Wire

program of statistical quality control, a control chart for each product seems a necessity. After experience has indicated that certain groups of products possess the same variability but differ in level of tensile strength, grouping of data on a "deviation-from-nominal" chart may be warranted. Later it may even be feasible to dispense with plotting the chart recognizing, however, the sacrifice of sensitivity to trends.

We must accept the concept that a given product is the result of a constant system as long as the material used and the operations performed are the same, relatively speaking, regardless of the point in time when the product is made. Then the determination of rational sampling will depend largely upon the technical and physical aspects of the operation. The wire-drawer has no control over the tensile strength of the wire he is producing; consequently his influence, insofar as sampling is concerned, is not a factor. The different types of machines on which the wire is drawn may have an influence on tensile strength but different machines of the same type usually will not. Therefore, sampling can be done on some convenient time schedule or on a lot or sublot basis. The possibility of requiring a screening operation such as testing each coil when the product is out-of-control must be considered. It certainly is not desirable to reduce sampling frequency to the point where, if the product is out-of-control, a large lot must be screened. In some plants where long runs of the same size and grade of wire are produced it has been found satisfactory to take two samples of four specimens from each machine each eight-hour turn. Where production lots are not of this magnitude, a sample of four from each load of about 5000 lbs. may be preferred.

Figure 3 shows a frequency distribution of actual tensile strength of size 0.148 inch upholstery spring wire. The computed average, the to-be-expected spread on the basis of plus or minus three standard deviations, and the specification limits for this product are also shown. In Fig. 4 we see a typical control chart on the tensile strength of the same product. Figure 5 illustrates the previously mentioned "deviation-from-nominal chart." Note that for a range of sizes the specification range is the same. The mean of the specification becomes our zero point and we plot the number of units (in this case, the p.s.i.) by which our actual data deviate from the specification mean. The actual data in this case are the average of four

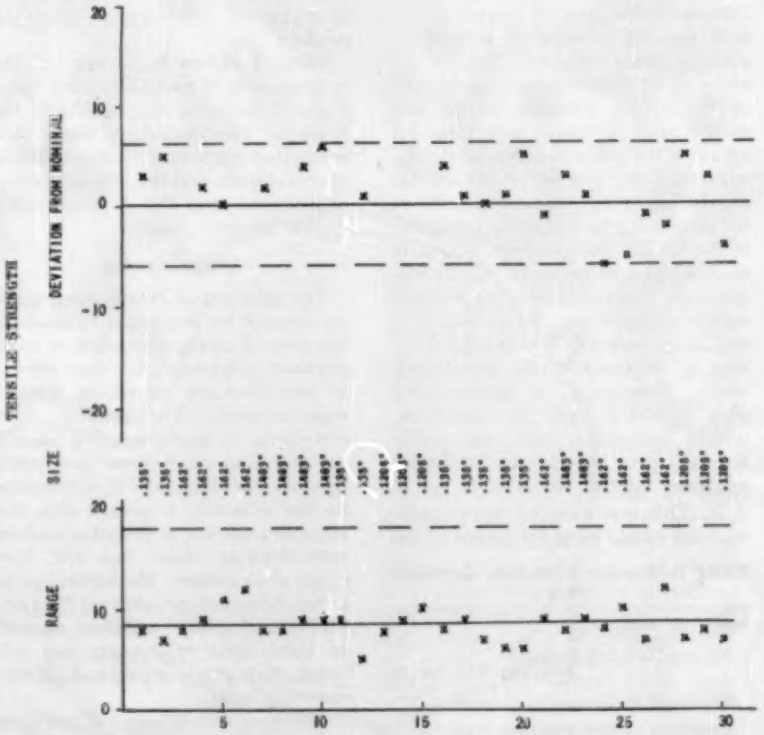

Figure 5—Control Chart of Deviation from Nominal Tensile Strength for 30,000 p.s.i. Tensile Range Spring Wire

specimens. The range is plotted in the conventional manner. This method of charting is feasible if the average range, that is, the variability of the various sizes covered by the chart, is of the same order of magnitude. Naturally, considerable valuable detail is lost, or at least not visually available, but the chart does give a good summary of the state of control of a number of items. For investigative work the chart for individual items is to be preferred.

Conclusion

We, at the American Steel & Wire Division, are convinced that statistical quality control techniques have a definite place in our scheme of quality control. While $\overline{X}$ and R charts are the most common tool, we also use correlation analysis, analysis of variance, and significance of difference tests quite frequently. The steel industry and particularly the steel wire industry cannot afford to fail to use these tools. Almost daily we see evidence, in the form of specification requirements, that our customers have awakened to statistical quality control. We intend to try to stay at least a jump ahead.

Fundamentals of Analysis of Variance

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Part III—Nested Designs in Analysis of Variance

Ed. note. This concludes Professor Hicks' article on the fundamentals of analysis of variance. Part I appeared in the August issue, p. 17-20, and Part II appeared in the September issue, p. 5-8.

Often in industrial experimentation an experimenter may confuse a factorial design, in which all levels of each factor are combined with all levels of every other factor, with another design known as a "nested" design. In this latter scheme, several levels of a factor may be nested within one level of another factor and be quite different for other levels of this same main effect. Recently an engineer asked about an experiment on a multi-headed machine in which there were four heads each supposedly doing the same job and he wished to study strain readings on each sample from each head and from five different machines. He argued that here was a case of five machines and four heads, so that a 5×4 factorial design and 20 experiments would provide the desired information if no repetitions were run within the 20 cells. If repeated four times, one has a 4×5 factorial design with four replications per cell, or 80 measurements. The model for this is:

$$X_{ijk} = \overline{X}' + M'_i + H'_j + (MH)_{ij} + \varepsilon'_{k(ij)}$$

where: $\overline{X}'$ is the common effect;

M'_i is the machine effect with $i = 1,2,3,4,5$;

H'_j is the head effect with $j = 1,2,3,4$;

$(MH)'_{ij}$ is the machine-head interaction effect;

$\varepsilon'_{k(ij)}$ is the random error with $k = 1,2,3,4$.

The data of Table I were recorded (after coding) and the analysis follows along the lines indicated in Part I where both heads and machines are considered fixed.

From this analysis one would conclude that there is no significant difference (at the 10 percent level) in the strain readings due to machines or due to heads but that there is a significant interaction between machines and heads.

Now a closer look at the problem indicates that each of the four heads was certainly not tried on all five machines, but actually the four heads were characteristic of the particular machine to which they belonged. Thus, there might be variation among heads but this would be within each machine as the four heads on another machine would, in fact, be entirely different heads. When such a situation occurs, the proper design is a nested design where the heads are nested within a machine, so the proper layout should be that shown in Table II.

In this table, the heads have been purposely numbered from 1 to 20 to emphasize that there really are 20 different heads to consider in this problem with four on each machine. This is essentially a one-way classification of data as there can be no interaction between ma-

TABLE I—Data and ANOVA for Sealing Machine Problem

		Machines				
		A	B	C	D	E
Heads	1	6 2 0 8	10 9 7 12	0 0 5 5	11 0 6 4	1 4 7 9
	2	13 3 9 8	2 1 1 10	10 11 6 7	5 10 8 3	6 7 0 3
	3	1 10 0 6	4 1 7 9	8 5 0 7	1 8 9 4	3 0 2 2
	4	7 4 7 9	0 3 4 1	7 2 5 4	0 8 6 5	3 7 4 0

Source	df	SS	MS	F	$F_{0.10}$*	EMS
Total	79	969.95				
Among Machines	4	45.08	11.27	1.05	2.04	$\sigma_e^2 + 16\,\sigma_m^2$
Among Heads	3	46.45	15.48	1.45	2.18	$\sigma_e^2 + 20\,\sigma_H^2$
M × H Interaction	12	236.42	19.70	1.84	1.66	$\sigma_e^2 + 4\,\sigma_{MH}^2$
Error	60	642.00	10.70			σ_e^2

(*10 percent level of significance used here)

TABLE II—Sealing Machine Problem—Nested Design

	Machine																			
	A				B				C				D				E			
	Head				Head				Head				Head				Head			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	6 2 0 8	13 3 9 8	1 10 0 6	7 4 7 9	10 9 7 12	2 1 1 10	4 1 7 9	0 3 4 1	0 0 5 5	10 11 6 7	8 5 0 7	7 2 5 4	11 0 6 4	5 10 8 3	1 8 9 4	0 8 6 5	1 4 7 9	6 7 0 3	3 0 2 2	3 7 4 0
Head Totals	16	33	17	27	38	14	21	8	10	34	20	18	21	26	22	19	21	16	7	14
Machine Totals	93				81				82				88				58			

chines and heads. The four heads are representative of a given machine and must be considered as heads from that machine only. The nested model can now be written as:

$$X_{ijk} = \bar{\bar{X}}' + M_i' + H'_{j(i)} + \varepsilon'_{k(ij)}$$

with $i = 1, \ldots 5; \quad j = 1, \ldots . 4; \quad k = 1, \ldots . 4.$

The $\bar{\bar{X}}'$, M'_1 and $\varepsilon'_{k(ij)}$ are the same as in the first model and $H'_{j(i)}$ indicates true differences among heads (j's) within a given machine (i). The methods of Part II can now be used to determine the proper significance tests to be run on this design. If machines and heads are considered fixed as before, the resulting EMS column would be found as follows:

	F i	F j	R k	EMS
M_i	0	4	4	$\sigma_e^2 + 16\ \sigma_m^2$
$H_{j(i)}$	1	0	4	$\sigma_e^2 + 4\ \sigma_H^2$
$\varepsilon_{k(ij)}$	1	1	1	σ_e^2

Here it is seen that one tests both the heads and machines vs. the error term. If, however, heads are considered random, then we would have:

	F i	F j	R k	EMS
M_i	0	4	4	$\sigma_e^2 + 4\ \sigma_H^2 + 16\ \sigma_m^2$
$H_{j(i)}$	1	1	4	$\sigma_e^2 + 4\ \sigma_H^2 +$
$\varepsilon_{k(ij)}$	1	1	1	σ_e^2

Machines would be tested against the term for heads within machines. In either case, the results would be quite different from the original analysis as no interaction is possible in such a nested design.

In the computations of the sums of squares care must be taken in a nested design that the SS for heads within each machine be corrected by the correction term for that machine only and not by the overall correction term. Then these five terms may be combined to give the SS among heads within machines. For the example cited:

$$\text{Total SS (as usual)} = 2990 - (402)^2/80 = 969.95$$

$$\text{Machine SS (as usual)} = \frac{(93)^2+(81)^2+(82)^2+(88)^2+(58)^2}{16} - \frac{(402)^2}{80} = 45.08$$

$$\text{Heads within Machines SS} = \frac{(16)^2+(33)^2+(17)^2+(27)^2}{4} - \frac{(93)^2}{16}$$

(for first machine)

$$+ \frac{(38)^2+(14)^2+(21)^2+(8)^2}{4} - \frac{(81)^2}{16}$$

(for second machine)

+ etc. for all 5 machines

$$= 282.87$$

Error SS (by subtraction) = 969.95 −45.08 −282.87 = 642.00, which is the same as in the previous analysis.

Thus, what was thought before to be head SS and machine-head interaction SS is really among-heads-within-machines SS, so the correct ANOVA is as shown in Table III.

The results of this correct analysis, when the design is recognized as a nested design, shows that at the 10 percent level of significance there is no significant machine effect, but there is a significant difference among heads within machines. Here then is evidence for more careful adjustment of the heads within the machine to obtain more homogeneous strain readings.

In some experimental work, the model considered may involve both a nesting within one or more factors, and other factors which are factorial (i.e. combined with all levels of the given factors). Such models would be referred to as "nested factorial" designs. The methods

TABLE III—ANOVA for Nested Sealing Machine Problem

Source	df	SS	MS	F	$F_{0.10}$	EMS
Total	79	989.95				
Among Machines	4	45.08	11.27	1.05	2.04	$\sigma_e^2 + 16\,\sigma_m^2$
Among Heads within Machines	15	282.87	18.85	1.76	1.60	$\sigma_e^2 + 4\,\sigma_H^2$
Error	60	642.00	10.70			σ_e^2

for determining the EMS column and hence the proper F tests to run are those cited in Part II as they allow for nested factors.

As an example of a nested factorial design, consider a problem by a former graduate student at Purdue who wished to improve on the number of rounds per minute on a Navy gun by a new method of loading the gun. His measured variable (X) was the number of rounds per minute and the main factor to be investigated was methods—the old vs. the new. However, all such loading depends on the team which loads the gun, so the investigator felt that the general physique of the men might have considerable effect on the resulting loading speed. Accordingly, he chose teams of men within three groups, where these groups were the slight men, average, and the heavy, more-rugged type. He was able to classify the men quite well in these three general groupings from Armed Services Classification tables. By a random choice of Navy ROTC students he was able to get three teams within each group which were thought to be representative of the group performance. It was felt that perhaps the slight-men (Group I) would do better on the new method than on the old method and that this might show up as a significant interaction between methods and groups. Considering all these factors, there were three things which might effect the number of rounds per minute: methods, groups, and teams within groups as well as some associated interactions and error. It was decided to make a repeat run on all of the teams to get a separate measure of error. The model can then be formulated as:

$$X_{ijke} = \overline{X}' + M'_i + G'_j + (MG)'_{ij} + T'_{k(j)} + (MT)'_{ik(j)} + \varepsilon'_{e(ijk)}$$

where

M'_i is the method effect, i = 1,2 (fixed effect);

G'_j is the group effect, j = 1,2,3 (fixed effect);

$(MG)'_{ij}$ is the method-group interaction effect;

$T'_{k(j)}$ is the teams-within-group effect (a random effect), k = 1,2,3 for all j;

$(MT)'_{ik(j)}$ is the interaction effect between methods and teams;

$\varepsilon'_{e(ijk)}$ is the random error, e = 1,2.

The data and ANOVA are shown in Table IV.

The EMS values and proper F tests are found by applying the methods of Part II which leads to Table V.

To test the hypothesis of no method-team interaction; i.e. that $\sigma_{MT}^2 = 0$, the MT mean square is compared with the error mean square by the F test with 6 and 18 degrees of freedom or:

$F_{6,18} = 1.79/2.31$, which is less than one and hence not significant. The team effect is tested by comparing the team mean square with the error mean square:

$F_{6,18} = 6.54/2.31 = 2.83$, which is just significant at the five percent level when compared to 2.66 in the F table.

The methods-groups interaction may be tested by comparing the MG mean square to the MT mean square as indicated by the EMS entries in Table V. Here

$F_{2,6} = 0.605/1.79$, which is less than one and hence not significant. The group effect is tested vs. the teams-within-groups line or:

$F_{2,6} = 8.02/6.54 = 1.23$, which is below the F table value at the five percent significance level.

TABLE IV—Data and ANOVA for Gun-Loading Problem

	Group I			Group II			Group III		
	Team 1	Team 2	Team 3	Team 4	Team 5	Team 6	Team 7	Team 8	Team 9
Proposed Method	20.2 24.1	26.2 26.9	23.8 24.9	22.0 23.5	22.6 24.6	22.9 25.0	23.1 22.9	22.9 23.7	21.8 23.5
Present Method	14.2 16.2	18.0 19.1	12.5 15.4	14.1 16.1	14.0 18.1	13.7 16.0	14.1 16.1	12.2 13.8	12.7 15.1

X = Number of rounds per minute

Source of Variation	df	SS	MS
Total	35	760.76	
Between Methods	1	651.95	651.95
Among Groups	2	16.05	8.02
M × G Interaction	2	1.19	0.60
Among Teams within Groups	6	39.26	6.54
M × T Interaction	6	10.72	1.79
Error	18	41.59	2.31

Finally the methods are tested vs. the MT interaction line, or:

$F_{1,6} = 651.95/1.79 = 364$, which is a highly significant value.

The results of the experiment then definitely show the superiority of the new method, which averages 23.58 rounds per minute as compared to 15.08 rounds per minute using the old method. There is also an indication of some variation in the average number of rounds per minute among the teams within the groups.

TABLE V—EMS Values on Gun-Loading Data

	F i	F j	R k	R e	EMS
M_i	0	3	3	2	$\sigma_e^2 + 2\,\sigma_{MT}^2 + 18\,\sigma_M^2$
G_j	2	0	3	2	$\sigma_e^2 + 4\,\sigma_T^2 + 12\,\sigma_G^2$
$(MG)_{ij}$	0	0	3	2	$\sigma_e^2 + 2\,\sigma_{MT}^2 + 6\,\sigma_{MG}^2$
$T_{k(j)}$	2	1	1	2	$\sigma_e^2 + 4\,\sigma_T^2$
$MT_{ik(j)}$	0	1	1	2	$\sigma_e^2 + 2\,\sigma_{MT}^2$
$e_{e(ijk)}$	1	1	1	1	σ_e^2

This example shows an application of statistical methods involving both a nested and a factorial design in the same experiment. The methods for obtaining the EMS values, which in turn indicate the proper tests to run, are perfectly general and follow from the mathematical model assumed in the experiment. It is necessary to agree long before the experiment is actually run as to what the important factors are which may effect the measured variable and whether these factors are fixed or random and whether they are factorial with one another or may be nested levels of another factor. Once there is substantial agreement as to the nature of these factors, a mathematical model can usually be set up and the methods presented here can be used to indicate what analysis will follow from the model that has been chosen. It is assumed that randomization procedures are used in the actual ordering of the experimental conditions on the units tested.

A Teaching Aid for Regression, Correlation, Analysis of Variance, and Other Statistical Techniques

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Introduction

It has often been said that lecturing is the poorest of the known methods of teaching. The truth of this statement is clearly demonstrated in courses in applied mathematical statistics where teaching aids of all types have proven to be extremely valuable. For many students, the treatment of a number whose source is known adds the necessary realism and interest to teach this subject effectively. A few of the more popular teaching aids are the Quincunx board and numbered chips for demonstrating variables control charts and colored beads for demonstrating attribute sampling plans. In recent years, quality control engineers have become interested in the more sophisticated statistical techniques such as the design and analysis of multivariable experiments and the correlation of numerical data. Very little, however, has been developed to aid in the teaching of these subjects. It is the aim of this article to describe an electrical device developed for this purpose.

Electrical models have been used effectively to teach various engineering subjects such as hydraulics and heat transfer. It seems reasonable that they should also prove of value in teaching various statistical techniques. The development of an electrical model or analogy for an industrial experiment can, by itself, be of great assistance to the student in the understanding of the composition of experimental data and the analytical problem it presents. Electrical models can be of further assistance in supplying valid and realistic data for sample problem analysis. One such model, called the *Process Variance Demonstrator*, is presented in this article.

The Process Variance Demonstrator

A photograph of the Process Variance Demonstrator is shown in Fig. 1*. The demonstrator measures 11 in. in width, 9½ in. in height, and 7 in. in depth. The heart of the demonstrator is the central meter which simulates the process dependent variable labeled Y. This is a standard six-inch meter which can be easily read up to a distance of ten

*The cost of the parts for this demonstrator is approximately $40 and the cost of the labor for construction is approximately $80.

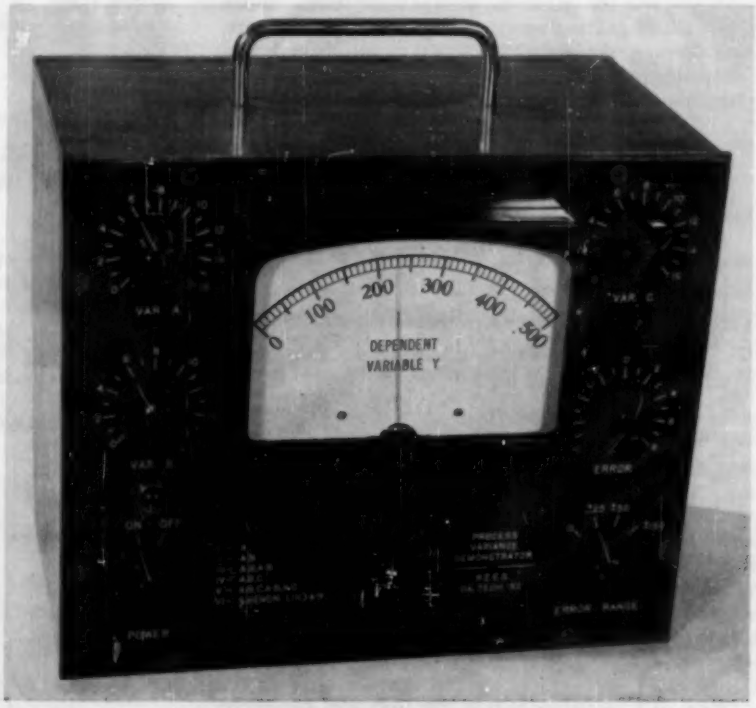


Figure 1—Process Variance Demonstrator

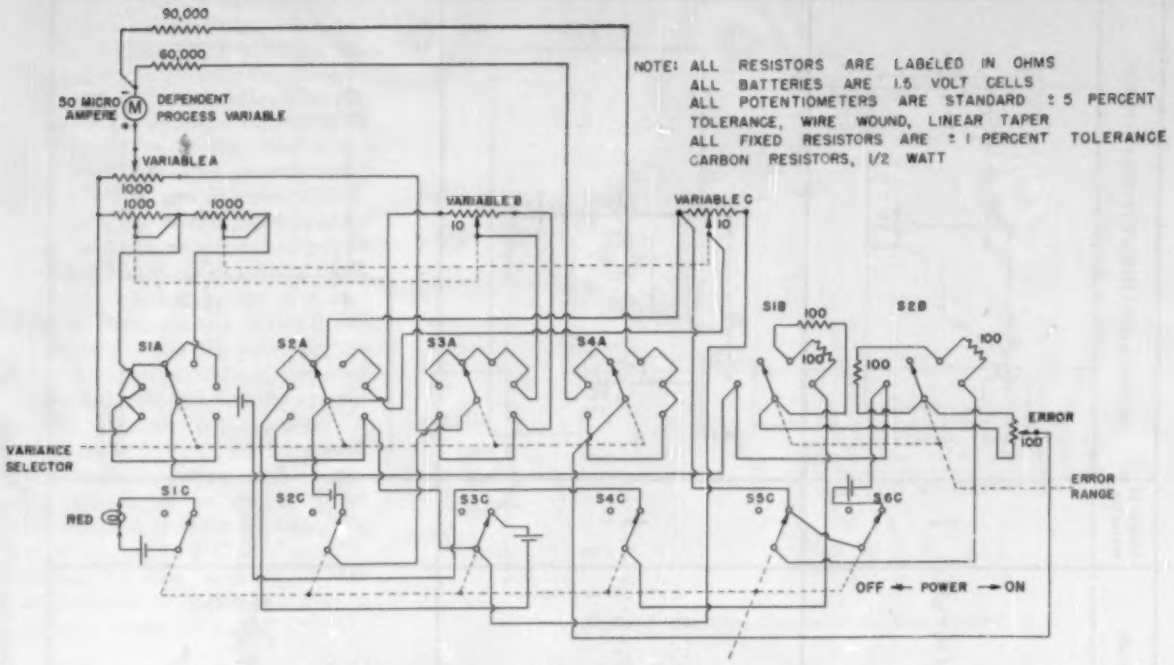


Figure 2—Wiring Diagram of the Process Variance Demonstrator

feet. On the sides of the meter are three dials labeled Variable A, Variable B, and Variable C. These dials simulate three independent process or experiment variables which can be set at any desired level from 0 through 16. These can, of course, be treated as fixed or random variables (Model I or Model II variables) depending on the method used in determining the dial settings. The effects of these independent variables on the process dependent variable Y can be noted by observing the meter reading. In conjunction with these three dials is the Variance Selector switch which has six positions. The significance of these six positions, as shown on the demonstrator, indicates that in position I, Y is a linear function of variable A only; in position II, Y is a linear function of A and B while, in position III, the interaction between A and B, noted A×B is added. In position IV, Y is a linear function of all three variables, A, B, and C, while in position V, two of the three possible first order interactions are added, i.e., A×B and A×C. In position VI, Y is a function of variables A, B, and their interaction A×B. In this latter position, Y is a linear function of A but a curvilinear function of B. This variable selector switch is set according to the type of process or experiment to be demonstrated.

To complete the realistic simulation of a process or experiment, a fourth dial is provided for introducing experimental error. The dial labeled Error is set at values ranging from −8 to +8 according to random drawings from a bowl of suitably numbered chips. The chip numbering and frequencies for a bowl of normally distributed chips is given in Table I. In conjunction with the error dial, there is a selector switch which permits a control of the range or magnitude of errors introduced by the error dial. In the 0 position, the error dial has no effect. In the ±25 switch position, rotation of the error dial from −8 to +8 effects the meter reading Y by a movement from about 25 units below to about 25 units above the correct Y value. The ±50 and ±150 switch positions operate in a similar manner.

The Process Variance Demonstrator thus provides a means for showing the effect of one, two, or three independent process variables on a dependent process variable, under realistic conditions in which experimental error is added in a random but controlled manner. Furthermore, the demonstrator permits the selection of processes in which the independent variables are interacting or non-interacting and are linear or nonlinear.

Electrical Circuits for Demonstrator

Before elaborating on possible applications, attention should be given to the electrical circuits which make up the demonstrator. The purpose of this discussion is to explain the basic mode of operation of the demonstrator so that its validity as a model for the analysis of variance, correlation, or other statistical techniques can be established. The demonstrator circuits have the following characteristics:

(1) The main effects A, B, and C are independent (additive) or interacting, depending on the position of the Variance Selector switch
(2) The experimental errors are always independent of the main effects A, B, C
(3) The experimental errors have a common variance whose magnitude is controlled by the Error Range switch
(4) The shape of the distribution of the experimental errors is controlled by the source of the random numbers used for the error dial settings.

The wiring diagram of the demonstrator is given in Fig. 2. To explain point (1) above, however, reference should be made to the equivalent circuit diagrams for the various Variance Selector switch positions shown in Fig. 3. An analysis of these diagrams will show that the main effects are independent (additive) or interacting, according to the posi-

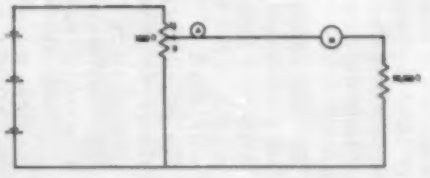
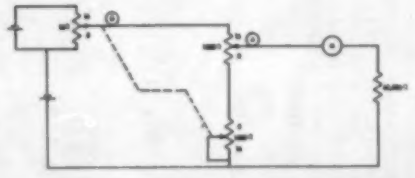
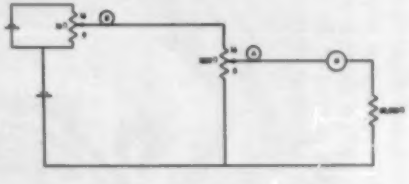
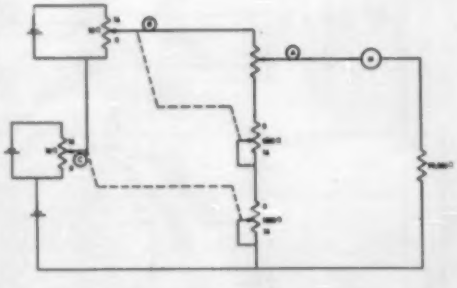
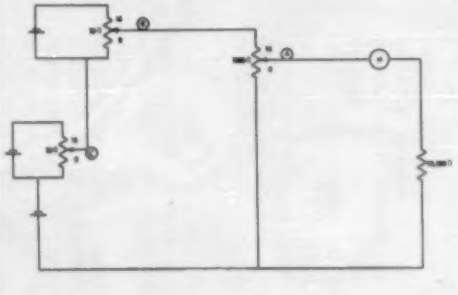
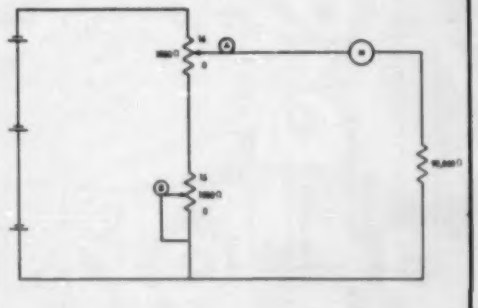
VARIANCE SELECTOR POSITION	EQUATION	SOURCES OF VARIANCE	EQUIVALENT CIRCUIT DIAGRAM WITH ERROR DIAL AT ZERO	VARIANCE SELECTOR POSITION	EQUATION	SOURCES OF VARIANCE	EQUIVALENT CIRCUIT DIAGRAM WITH ERROR DIAL AT ZERO
I	$y = 31.3\,X_A$	A		II	$y = 15.6\,(X_A + X_B)$	A B	
III	$y = 15.6\,X_A + 0.98\,X_A\,X_B$	A B A x B		IV	$y = 10.4\,(X_A + X_B + X_C)$	A B C	
V	$y = 0.652\,(16.0\,X_A + X_A\,X_B + X_A\,X_C)$	A B C A x B A x C		VI	$y = 500.0\,\frac{X_A + X_B}{X_B + 16}$	A B (non-linear) A x B	

Figure 3—Simplified Circuit Diagrams and Equations for the Six Variance Selector Switch Positions

tion of the Variance Selector switch. For example, the main effects A and B are independent in Variance Selector position II because the currents flowing through potentiometers A and B are constant, regardless of their respective settings. This is accomplished by the potentiometer ganged with B and in series with A. The resistance of this potentiometer varies with the movement of potentiometer B so that the current flowing through potentiometer A is constant and thus renders A and B additive. In position III, however, the ganged potentiometer is removed from the circuit and thus the current flowing through potentiometer A varies with the position of potentiometer B. The effect of A, therefore, depends on the level of B and thus interacts with B. Positions IV and V operate in a similar manner. Position VI was included in the demonstrator to make available a nonlinear electrical model.

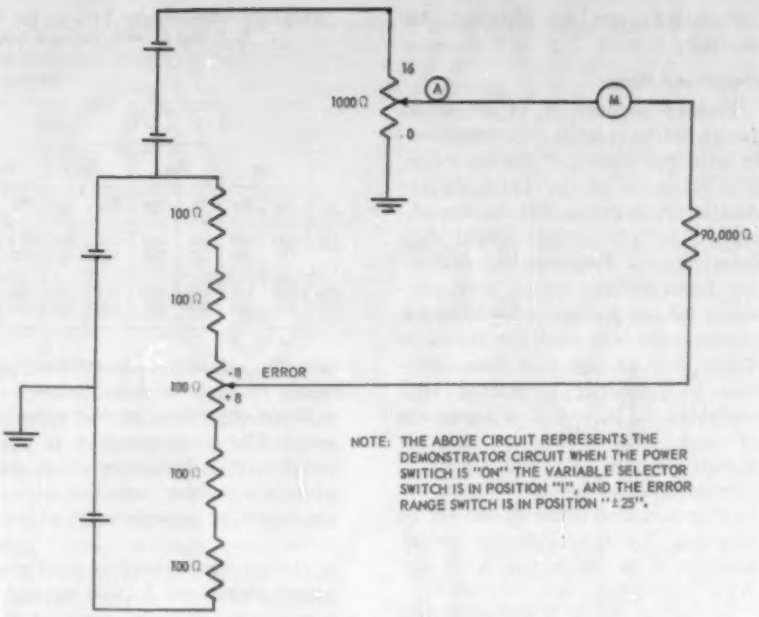


Figure 4—Simplified Diagram of the Error Circuit

TABLE I—Chip Numbering and Frequencies of a Normal Distribution with a Mean of Zero and Standard Deviation of 2.76

Chip Number	Frequency
8	½*
7	1
6	3
5	6
4	10
3	16
2	22
1	27
0	28
−1	27
−2	22
−3	16
−4	10
−5	6
−6	3
−7	1
−8	½*
Total	199

*A frequency of ½ was obtained by marking one side of the chip +8 and the other side −8.

An analysis of the circuit shown in Fig. 4 will show that points (2) and (3) above are satisfied by the demonstrator error circuit. Since the meter used in the demonstrator draws a negligible amount of current (50 μamp movement,) the error circuit is essentially isolated from the remainder of the demonstrator circuits, and thus its effect is independent of the dial settings for the main effects A, B, and C. The range of the errors introduced is controlled by varying the number of 100 ohm resistors in series with the error potentiometer, the error range increasing as the number of these resistors are decreased. For a given Error Range switch setting, the range of errors or the variance of the errors is constant and independent of the main effects A, B, and C. The validity of point (4) above is obvious. Since these four points are the basic assumptions underlying the analysis of variance and correlation, the validity of the demonstrator as a model for these techniques is established.

Demonstrator Applications

From the foregoing discussion, it follows that the demonstrator can be used to simulate experimental situations by an electrical analogue, and it can further be used to obtain realistic and valid data for analysis by regression, correlation, analysis of variance, or other statistical techniques.

Regression and Correlation

To demonstrate regression or correlation, one would first select the desired equation from Fig. 3. Variance Selector switch positions I and II provide simple linear equations of the form $y = bx$ and $y = a + bx$, respectively. For multiple correlation, a variety of equations are available. Position IV can be used to furnish a simple multiple correlation model of the form $y = a + bx_1 + cx_2$. The exact procedure for setting dials A, B and C would depend on the nature of the demonstration. The settings could be varied either in some orderly fashion or at random, according to selections from a bowl of chips. Similarly, the error dial would be reset for each reading of Y according to a random selection from a bowl of chips such as the one listed in Table I. By this procedure, data which satisfy a variety of basic

TABLE II—Analogous Classical and Latin Square Experiment Designs

Latin Square (n = 9 tests)				Classical Design (n = 9 tests)			
	A_1	A_2	A_3	Variable	Tests		
B_1	C_2	C_3	C_1	A	*$A_1B_1C_1$	$A_2B_1C_1$	$A_3B_1C_1$
B_2	C_1	C_2	C_3	B	*$A_1B_1C_1$	$A_1B_2C_1$	$A_1B_3C_1$
B_3	C_3	C_1	C_2	C	*$A_1B_1C_1$	$A_1B_1C_2$	$A_1B_1C_3$

*These tests are replications used to establish estimate of experimental error.

assumptions can be obtained for analysis.

Experimental Design

Various aspects of experimental design can be treated quite effectively with the electrical demonstrator. The efficiency of the Latin Square design, for example, can be demonstrated by comparing sample data for a classical design and an analogous Latin Square design, with universe values. Sample designs which contain nine tests each are shown in Table II. Although this demonstration is ordinarily conducted with variables A, B, and C independent of each other (Variance Selector switch position IV), the effects of interactions on these two designs can be demonstrated quite effectively by choosing Variance Selector switch position V in which the A×B and A×C interactions are significant.

To further aid in a demonstration of this type, a set of three-dimensional models have been constructed for the equation built into the demonstrator for Variance Selector switch position V, i.e.,

$$y = 0.65\ (16.0X_A + X_AX_B + X_AX_C).$$

These models, shown in Fig. 5, have the independent variable A plotted on the abscissa, variable B on the ordinate and the dependent variable Y on the vertical or response axis; the independent variable C is treated as a parameter at a different level in each of the three models. Alligator clips are placed on the model at the points chosen for the Latin Square and Classical Designs shown in Table II. For an unsophisticated presentation of elementary experimental design principles, these physical models have proven quite effective.

Analysis of Variance

The demonstrator is ideally suited to the study of analysis of variance. Because of the importance of this subject, and to present a general evaluation of the demonstrator, a detailed example is given below.

TABLE III—Random Numbers Used for Error Dial Settings for the Sample Data Shown in Tables IV and V*

	A_2		A_{14}	
	B_4	B_{12}	B_4	B_{12}
C_2	+3	0	+4	−3
	0	+5	0	+1
C_{10}	+3	+3	−2	+4
	−1	−2	+3	0

*These numbers were obtained by random drawings from the chip distribution given in Table I.

TABLE IV—Demonstrator Data for the Indicated Levels of the Independent Variables A, B, and C, with Variance Selector Switch in Position IV (A, B, C)

	ERROR RANGE SETTING															
	0				±25				±50				±150			
	A_2		A_{14}		A_2		A_{14}		A_2		A_{14}		A_2		A_{14}	
	B_4	B_{12}	B_4	B_{12}	B_4	B_{12}	B_4	B_{12}	B_4	B_{12}	B_4	B_{12}	B_4	B_{12}	B_4	B_{12}
C_2	133	205	251	324	148	209	272	316	154	209	282	307	191	206	326	265
	131	209	251	325	134	231	253	334	132	244	252	336	130	302	250	344
C_{10}	169	244	283	358	184	257	279	376	191	268	273	388	228	299	244	432
	165	240	286	357	165	236	300	360	161	231	310	359	146	202	341	356

- *State objectives of the experiment.* The demonstration is initiated with a discussion of an appropriate problem together with a statement of experimental objectives.
- *Design experiment to meet the stated objectives.* In this example a replicated factorial design containing three independent variables at two levels each is chosen and is shown in Table III. The levels of the variables, A, B, and C, are indicated by the subscripts; the numbers given in the body of this table are random drawings from the chip distribution given in Table I and are used for the error dial settings in this demonstration.

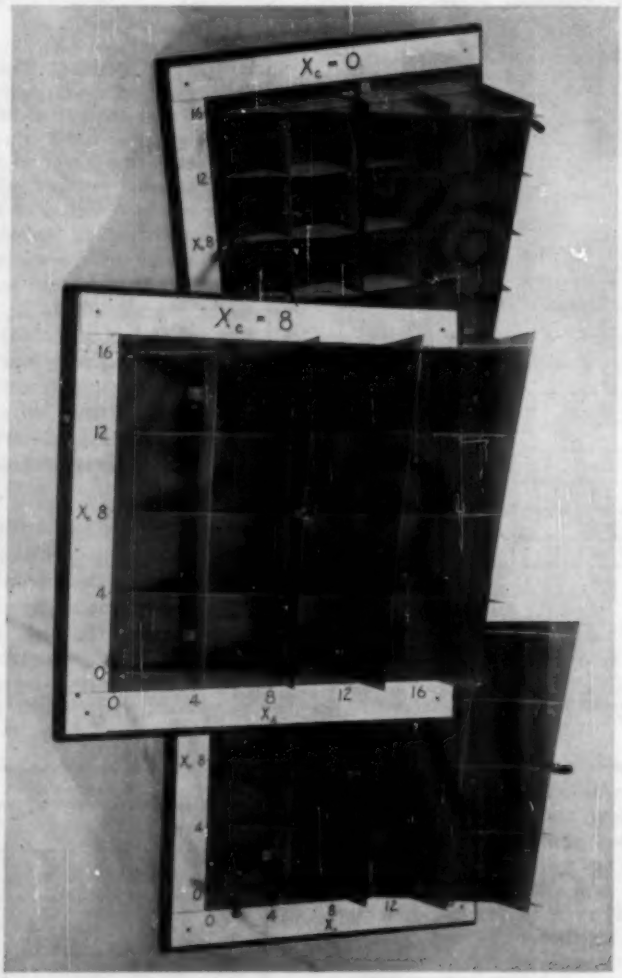


Figure 5—Physical Models Representing the Demonstrator Equation with the Variance Selector Switch in Position V

• *Write model equation for the experiment.* The three independent variables A, B, and C are treated as fixed level or Model I type variables in this example.

• *Collect the data.* Great care is taken to collect the data in the proper manner with emphasis on the need for resetting each independent variable dial for every test observation to insure that each reading of the dependent variable, Y, is independent and includes the random error introduced by the slight non-reproducibility of the demonstrator dial settings. The importance of carrying out the experimental tests in random order is also emphasized and is included as part of the demonstration.

Meter readings of the dependent variable Y were obtained for this design at all four settings of the error range switch and for positions IV and V of the Variance Selector switch. The readings for position IV in which no interactions are present are given in Table IV, and for position V in which the A×B and A×C interactions are present, in Table V.

TABLE V—Demonstrator Data for the Indicated Levels of the Independent Variables A, B, and C, with Variance Selector Switch in Position V (A, B, C, A×B, A×C)

	ERROR RANGE SETTING															
	0				±25				±50				±150			
	A_8		A_{14}		A_8		A_{14}		A_8		A_{14}		A_8		A_{14}	
	B_4	B_{12}	B_4	B_{12}	B_4	B_{12}	B_4	B_{12}	B_4	B_{12}	B_4	B_{12}	B_4	B_{12}	B_4	B_{12}
C_6	37 36	46 48	234 236	299 301	52 40	49 71	254 240	291 307	61 39	49 84	264 240	283 310	98 36	46 145	312 236	243 320
C_{10}	43 40	51 50	266 266	330 330	58 40	68 47	262 279	346 333	65 36	76 42	256 286	354 333	102 23	111 14	226 321	403 330

• *Analyze the data and report the results.* The mean square for each source of variance has been computed and is presented in Table VI together with a summary of the significance levels of these factors in Table VII. These results follow the expected pattern of significance and demonstrate the effect of the magnitude of the experimental errors on the sensitivity of the analysis of variance in detecting significant main effects and interactions. For example, the effect of variable C was masked by the errors for the ±150 error range setting in Table IV and the ±50 and ±150 error range setting in Table V. The A×B and A×C interactions in Table V were masked in a similar manner for the ±50 and ±150 error range setting.

A check on the residual mean squares given in Table VI indicate that they are consistent with the values introduced in the error dial. The residual variance for the zero error range setting, which is a measure of the errors introduced by the slight non-reproducibility of the independent variable dial settings and in the reading and functioning of the dependent variable meter, are quite small. A discussion of these values has proven to be quite enlightening to the student.

Summary

The purpose of this article is to stimulate interest in the use of electrical models as teaching aids for various statistical techniques and to synthesize valid and realistic numerical data for statistical analysis. It should be pointed out, however, that the synthesis of data and subsequent reanalysis is an extremely valuable teaching aid and its use is recommended even if one cannot afford an elaborate electrical demonstrator.

TABLE VI—Mean Squares for the Data Given in Tables IV and V

Variance Selector Switch Position IV, Significant Factors A, B, and C

Source of Variance	Degrees of Freedom	ERROR RANGE SETTING			
		±0	±25	±50	±150
A	1	55,107.5625	53,592.25	52,555.5625	45,582.25
B	1	21,978.0625	21,316.00	21,535.5625	18,906.25
C	1	4,658.0625	4,225.00	4,389.0625	3,422.25
A×B	1	3.0625	25.00	105.0625	380.25
A×C	1	3.0625	25.00	105.0625	1,260.25
B×C	1	0.0625	20.25	76.5625	756.25
A×B×C	1	0.0625	132.25	351.5625	3,306.25
Residual	8	3.9375	179.00	495.5625	3,517.00
Total	15	5,452.0958	5,384.5167	5,533.8625	6,783.3167

Variance Selector Switch Position V, Significant Factors A, B, C, AxB and AxC

Source of Variance	Degrees of Freedom	ERROR RANGE SETTING			
		±0	±25	±50	±150
A	1	228,245.0625	222,548.0625	219,492.25	206,116.00
B	1	5,513.0625	5,148.0625	5,041.00	4,160.25
C	1	1,207.5625	1,040.0625	870.25	552.25
A×B	1	2,907.5625	2,425.5625	2,116.00	1,296.00
A×C	1	689.0625	1,008.0625	1,332.25	3,721.00
B×C	1	1.5625	33.0625	100.00	812.25
A×B×C	1	0.0625	126.5625	324.00	3,249.00
Residual	8	1.4375	142.9375	397.00	3,459.6250
Total	15	15,911.0292	15,565.3958	15,496.7833	16,505.5833

TABLE VII—Significance Levels for the Mean Squares Listed in Table VI

Source of Variance	Degrees of Freedom	Table IV Data Significant Factors A, B, and C				Table V Data Significant Factors A, B, C, AxB, and AxC			
		ERROR RANGE SETTING				ERROR RANGE SETTING			
		±0	±25	±50	±150	±0	±25	±50	±150
A	1	***	***	***	**	***	***	***	***
B	1	***	***	**	*	***	***	**	
C	1	***	***	**		***	*		
A×B	1					***	**	*	
A×C	1					***	*		
B×C	1								
A×B×C	1								

Notation:
* Significant at the 5.0% level
** Significant at the 1.0% level
*** Significant at the 0.1% level

SUPERVISOR'S CIRCLE

PAUL A. ROBERT, *Editor*

A new department is being added to IQC to make it a more valuable publication to the inspection manager who is daily confronted with the many practical problems that arise in the administration of a quality control program.

In the past twenty years, the inspection function has emerged from a policing function to more of an engineering and planning function. Where at one time the inspection department concerned itself solely with the compliance of the product with specifications, today the inspection department is concerned with and often involved in the establishment of specifications, engineering and management policy and practice as it effects product quality, and of course the process controls and inspection functions that assure the flow of quality material from raw material to the finished product.

Management has come to realize that quality control concerns practically every department in the business. The Purchasing Agent when he selects a vendor, the Maintenance Department when it sets up the machine tool maintenance schedule, the Tool Engineering Department when it designs the tools and lays out the manufacturing procedure, the Production Department when it establishes the minimum reorder point, the Personnel Department when it hires new operators, the Production Foreman when he trains his men—all are performing acts which have a marked effect on the quality of product the shop produces.

The successful inspection manager is the man who can, with the aid of the front office from time to time, sell his fellow executives on the fact that getting out a quality product is as much their responsibility as his and that many of the decisions which they make every day are prime factors in determining what the ultimate quality of the product will be. This selling consists mainly of pointing out by concrete example to other departments how a quality accident resulting in much scrap and rework resulted from a misinterpreted print, how standards had to be lowered and sub-standard material used because the quantity in stock was so low the parts could not be rejected, how a quantity of expensive parts were scrapped because the foreman did not instruct the operator properly, how by not tooling the job properly an out-of-control condition continually persists, and so on and on.

On the other hand, the inspection manager is never allowed to forget that he "adds to the cost but not the value of the product," that he is a "necessary evil." Inspection is like insurance; you are never quite sure you have enough and never quite sure you do not have too much. The cost of quality, like the value of quality, is difficult to determine.

In a thoroughly "quality minded" organization, manufacturing an established product for a relatively stable market and a product thoroughly familiar to the engineering and manufacturing organization, it is conceivable that very little inspection would suffice, and the inspection manager would be justified in maintaining "token" controls and periodic "audits" of quality. The amount and type of protection that we should plan to build into the quality controls in our plants, ways of reducing the cost of quality with little or no loss of protection, and the impact of policies and practices of other departments on product quality, will be the subject of subsequent articles.

EDITORIAL NOTE

Activation of this department has been endorsed by the Editorial Board for the purpose of helping to fulfill a reader interest need not always adequately met by articles published in IQC.

Modern industrial quality control embraces anything and everything—including statistical science—that contributes to striking a profitable balance between the factors of quality and the cost of quality. Important as sound statistical strategies are in the achievement of this objective, they are not the whole story. This new department is opened to our readers as a medium for giving expression to the discussion of the many essentially *non*-statistical aspects of a good quality control program.

The department will operate under the editorship of Paul A. Robert. It will be his responsibility to suggest topics appropriate for discussion, to solicit copy from readers who have an active interest in these aspects of quality control, and to plan the timing and sequence of publication of submitted material. Initially, it is anticipated that the department should serve as a forum for the pro and con discussion of some of the problems outlined in this current issue. It is, however, entirely possible and desirable that eventually the activities of the department will prompt the submission of formal manuscripts justifying publication as contributed articles to IQC.

Here is an opportunity and an invitation. It is up to our readers to give Paul the response and cooperation he must have to get this vital part of the total quality control function properly developed and presented in IQC. The Editorial Board recognizes the need and has moved to meet it, contingent only on the cooperation of those who do something constructive about it. We have a capable editor in charge who brings both experience and enthusiasm to his assignment. Get in touch with him about the topics you want to have discussed, and contribute your own ideas and experiences.

This can be an important step in strengthening the usefulness of our journal in the quality control field.

Will you accept the challenge?

Mason E. Wescott, Chairman
Editorial Board, ASQC

The editor agreed to take on this new assignment because he felt that this area of inspection management needed exploring and he was promised by numerous Chief Inspectors, Quality Managers, and Directors of Quality Control that they would contribute their experiences to this column. It is with faith in the future contributions of these men that we are going ahead.

We hope that our readers will seize this opportunity to indicate their desires in this area and help the editor in his search for material of interest.

In a future issue we will discuss the relationship of engineering and inspection, with particular emphasis on the interpretation of blueprint specifications.

Some of the subjects which have been proposed for future issues are:

Metrology—the science of measurement and the gages involved in mechanical inspection.

Work Simplification and Standards—Applying these principles in the field of inspection, and the establishment of standards which can be used for performance measurement and estimating inspection cost.

Gage Control—practical systems in current use for assuring the continued accuracy of gages and measuring instruments. Also a discussion of gage wear allowance, gage tolerances in relation to part tolerances, etc.

Tool Control—methods of inspecting tools, pilot runs, last piece inspection. Tool inspection as a function of quality control.

Handling of Defective Material—Relationship of inspection and engineering in handling departures from specification.

Relationship with Manufacturing Engineering—Use of process capability studies in manufacturing planning, relation of inspection and tool engineering in trouble-shooting new tooling and processes.

Process Controls—Operator inspection vs. process inspectors. Practical experiences using $\bar{X}$ and R charts, pre-control, sampling plans, etc. as process control. Toll gate vs. final parts inspection.

Quality Reports to Management—Effectiveness of reports to management. Getting corrective action, feed back of information to management and engineering. Measuring cost of quality. Measuring field performances, customer complaints, etc.

Organization of Inspection Department—Centralized vs. decentralized control, operator responsibility for quality, authority of inspection organization, inspector training, eliminating bias in inspectors, etc.

Local Section News

". . . BUT NOT FORGOTTEN"

ALLENTOWN-BETHLEHEM A summer outing and clam bake was held by the section on Aug. 17. An excellent dinner, refreshments, and a social evening were enjoyed by 60 members, their families, and guests. It was the concensus that this summer meeting afforded a refreshing change of pace; quality control was referred to only in connection with the excellency of the meal, and statistics entered the picture only long enough for a count of heads before the meal was served.

BINGHAMTON An executive committee meeting was held Aug. 2. Plans were made to include more sections in the one-day clinic to be held Mar. 5, 1957. The program for the 1956-57 season was also presented to the committee. A new meeting place was announced at this meeting. This year the section will meet in the Endicott American Legion Hall.

CINCINNATI On Aug. 6 at Champion Paper's Thompson Park, Hamilton, Ohio, the section's executive committee was privileged to attend a meeting with the Hamilton subsection's executive committee. Joint plans were discussed for the coming year's activities. The evening was made more enjoyable by the presence of several of the members wives.

In August the detailed program was presented for the entire year. Each meeting—third Wednesdays—will be preceded by dinner and a coffee talk. The coffee talks are on subjects of current interest and are designed to be entertaining as well as instructive. The technical sessions are to be presented by some of the outstanding figures in quality control and are scheduled to cover the range from "hardware" to "sensory evaluations."

Chairman Dave Birch has emphasized at the last two executive committee meetings that education, attendance at meetings and hospitality are this year's watchwords for Cincinnati. There has been general agreement that a sustained effort should be made to get section members better acquainted with each other.

The annual series of educational lectures stressing elementary quality control is being offered at the New Woodward High School. The course is designed for those who are unfamiliar with SQC to get a sound introduction to principles.

The Hamilton subsection is also offering a series of educational talks in cooperation with the Adult Education Council of Hamilton. Mel Snow, director of quality control for NuTone, is the instructor.

DELAWARE The executive committee met at the home of section secretary Ed Niedzielski on Aug. 23 to continue with the formulation of plans for the 1956-57 season. The programs and speakers for the regular monthly meetings promise a most interesting and diversified schedule.

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HARRISBURG The third summer meeting of the executive committee was held at the Aircraft-Marine Products plant at Harrisburg on Aug. 15. Favorable reports were presented by all the chairmen with the program and arrangements committees to be specially commended for lining up such an excellent list of speakers and meeting places at this early date.

Plans are progressing nicely for the courses in quality control to be given again this year by the Harrisburg section. Both basic and advanced courses will again be given. The courses will definitely be given in Lancaster, but will also be presented in York and/or Harrisburg if the interest warrants it.

LOS ANGELES The section was host to 523 enthusiastic quality control users at the Third Annual Western Quality Control Conference. In attendance were such notables as Dale L. Lobsinger, ASQC President; and ASQC Vice Presidents Leon Bass, E. E. Schiesel, and J. Y. McClure. The equally noted speakers included Major General Leslie E. Simon, The Carborundum Co., and Prof. Lloyd A. Knowler, State University of Iowa. (See photo on opposite page.)

LOUISVILLE The advanced course in quality control and data analysis with Burr Stanton and Allen Greene as instructors, has its full enrollment of 25 persons. This is the first time that the course has been offered.

Local news of our section and members is published monthly by the *Louisville Engineer and Scientist,* a magazine published by the Louisville Scientific Council. It reaches 2500 technical people in the area and makes an excellent medium for obtaining new members.

NEW HAVEN The executive committee of the New Haven section met at the home of Chairman J. L. McVay on Aug. 1 and completed the program for the 1956-57 season. It will include two clinic sessions, a panel discussion on quality problems and five nationally known speakers on quality control.

ROCHESTER The membership of the section is aware of the outstanding job done by our outgoing officers during the 1955-56 term, and wishes to thank: president Cuyler J. Hawkes, Eastman Kodak Co.; vice president Hubert C. Minard, Bausch & Lomb Optical Co.; secretary-treasurer Elmer F. Lalonde, Eastman Kodak Co. We also owe our thanks to Russell C. McCarthy, manager, Industrial Management Council, and his capable staff, for a great deal of help.

ST. LOUIS The executive committee had another meeting to complete the plans for the various activities scheduled for 1956-57.

The section began a beginner's course in statistical quality control at the Hotel Melbourne. The course runs for ten consecutive weeks and will end in December.

SOUTH TEXAS The first executive committee meeting for 1956-57 was held Aug. 1. The program for the year was discussed and the duties and responsibilities of the officers and committee chairmen were discussed.

TORONTO Members of the section participated in the Canadian Broadcasting Corporation's program "Business and Labor Review" over the Trans-Canada network on July 26, in which quality control and the activities of the Society in Canada were featured.

The above photo was taken at the Monday luncheon held during the recent Third Annual Western Quality Control Conference in Los Angeles. Shown standing at the speaker's table are, left to right: D. R. Archibald, Convair-Astronautics, San Diego section; H. C. Todt, North American Aviation—Autonetics, Los Angeles section; D. M. Hull, United Airlines, San Francisco section; R. P. Palmer, Hughes Aircraft Co., Tucson; L. W. Ball, Consultant (reliability and quality assurance), Los Angeles section chairman; General C. A. Shoop, vice president of Hughes Aircraft Co.; Maj. Gen. L. E. Simon of the Carborundum Co. and featured speaker; J. Y. McClure, Convair-Ft.Worth; F. H. Squires, Topp Industries, Inc.; U. A. Engberg, USAF San Bernardino AMA, San Bernardino section; B. R. Swarts, Convair-San Diego, San Diego section; D. Hawks, Hughes Aircraft Co., Tucson; H. B. Epstein, Convair; I. A. Spitzer, Kaiser Steel Co., San Bernardino section.

WESTERN MASSACHUSETTS Education chairman Carl Baumann has conducted a survey by polling the 70 members of the section as to the advisability of conducting a course in "operation research." The results of this poll will not be known for several weeks because of time allowed for answering.

WORCESTER The executive committee and area chairmen met Aug. 21 at the Worcester YMCA to set up final plans for the coming year. Warren Arnold, chairman of the section, presided.

"... CAST THEIR SHADOWS BEFORE"

ALLENTOWN-BETHLEHEM The regular monthly meeting will be held in the Oriental Room of Walp's Restaurant, Allentown, on Nov. 14. The program will include a talk on "A dynamic quality training program" by William A. MacCrehan, of Bendix Aviation Corp.

BINGHAMTON The speaker at the Nov. 9 meeting will be A. C. Rosander, chief, sampling and estimating section, Internal Revenue Service. His subject will be "Probability statistics applied to the control of the tax return operations."

BUZZARDS BAY Ralph E. Wareham of Ralph E. Wareham and Associates, consultants in Chappaqua, N. Y., is to speak on "Quality control management" at the Nov. 13 meeting.

CINCINNATI As an expanded special events program opener, a plant tour is scheduled for Oct. 31. Members are urged to watch for announcement of the plant to be visited. An informative, "refreshing" evening is promised.

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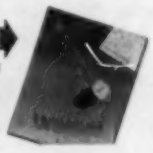

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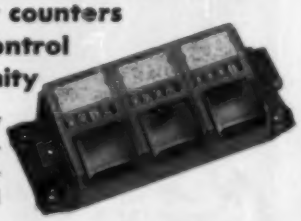

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CORNING -ELMIRA The next meeting of the section will be held at the Baron Steuben Hotel in Corning on Monday, Nov. 12. The section is to be honored to have as speaker for this dinner meeting John M. Allderige, technical advisor of the industrial engineering division of the Eastman Kodak Co., Rochester. His topic will be "Designing work measurement studies." Members of the local section of the American Institute of Industrial Engineers will be invited to this meeting.

DALLAS -FORT WORTH W. D. Witemeyer, manager, fixed gage and inspection room, instrument division of The Sheffield Corp., will address the section on Nov. 8 at Arlington State College on "The five echelons of accuracy."

DAYTON The regularly scheduled meeting for November will be held Nov. 8 at the Standard Register Co. The speaker for this meeting will be Dr. A. F. Johnson of the Buckeye Cellulose Co. speaking on the "Application of QC of continuous processes in pulp and paper."

DELAWARE The November meeting of the section will be held at the Lord DeLaWarr Hotel on Thursday, Nov. 1. Details of this meeting will be announced at a later date.

GEORGIA On Tuesday, Oct. 30, at 7:45 pm in Room 1833 of the Hurt Building, Atlanta, William J. Masser, manager, quality control engineering service, General Electric Co., Schenectady, N. Y., will present "Programming the quality control engineering job."

GREATER MUSKEGON The October meeting of the section will be a dinner meeting at Bill Sterns' Steak House. Vincent Nichols of the Bendix Aviation Corp., South Bend, Ind., will be guest speaker. His topic will concern statistical quality control in the aircraft business. A movie on jet engines and planes will complete the evening program.

HARRISBURG The second meeting of the year will be held at the Yorktowne Hotel in York, Pa., on Wednesday, Nov. 7. The speaker for the evening will be E. H. Robinson, director of quality, Johnson & Johnson, Chicago, whose topic will be "Statistical techniques for adjusting production plans to sales trends." This is something just a little different and certainly should be beneficial to many of us.

KANSAS CITY The section will hold the November meeting at the Blue Hills Restaurant on Wednesday the 7th. Following the dinner and business meeting, Dr. A. V. Feigenbaum, manager, quality control, General Electric Co., Schenectady, N. Y., will provide the feature program of the evening. Dr. Feigenbaum's subject will be "Total quality control."

LOS ANGELES On Nov. 14 the section will be honored by the presence of Dr. A. V. Feigenbaum, manager, quality control, General Electric Co., Schenectady, N. Y., who will discuss "Total quality control."

MILWAUKEE On Nov. 14 if Dale L. Lobsinger of United Airlines and ASQC President, will be as happy to be our speaker as we will be to have him, the meeting will be a success. Mr. Lob-

singer will talk about his favorite topic, "QC in administrative areas." His enthusiasm and experience will make this a wonderful opportunity to learn about the latest in this field in a painless way. Beer will be served at 5:30 pm, followed by a buffet dinner at 6:30 and the speaker of the evening at 7:30. All will take place at the Stratford Hotel.

The education and training committee announces a new series of talks on the intermediate level of SQC for those who would like to build on their basic course. These informal educational training sessions will be held from 5-6:30 pm immediately before our dinner and regularly scheduled meeting. Those leading the discussions will be members of the section with occasional invited speakers. The program is: I. W. Schoeninger, "The t-test," Oct. 22; J. Schaefer, "The F-test," Nov. 14; W. A. Golomski, "The Chi-square test," Jan. 21; A. E. Jakel, "Analysis of variance," Feb. 18; L. Neuman, "Analysis of variance," Apr. 15. All meetings will be held at the Stratford Hotel and there is no charge.

NEW HAVEN On Nov. 13 Erwin Taylor, Atomic Fuel Dept., Westinghouse Electric Corp., will be the guest speaker at the monthly meeting of the section. Mr. Taylor's subject will be "Discovery sampling." The meeting will be held in the cafeteria of the Greist Mfg. Co., New Haven.

NORTHEASTERN INDIANA A plant tour of the General Electric Co.'s facilities at Decatur, Ind. is planned for Nov. 8. J. E. Goldress, General Electric Co., Fort Wayne, will supply the speaker for the meeting which precedes the plant tour.

RHODE ISLAND The October meeting is being planned as a joint meeting with the Purchasing Agents Association of Rhode Island. The guest speaker is H. J. Jacobson, quality control manager at the P. R. Mallory & Co. Inc., of Indianapolis, Ind. Mr. Jacobson's talk is entitled: "Quality control for purchasing agents."

ROCHESTER In October the section will be addressed by Edward J. Oakley, Delco-Remy Div., GMC. His subject will be "Introduction to statistical quality control." Our scouts inform us that Mr. Oakley has added some new twists which should produce wide interest.

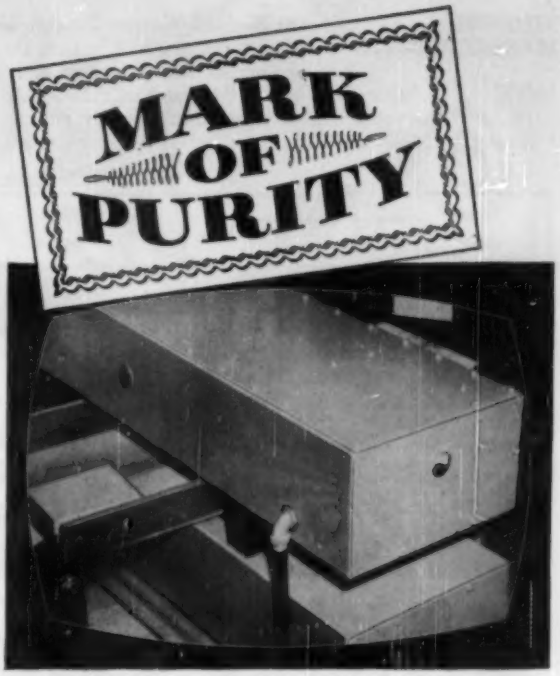
On Nov. 13 the gaging and measurement sub-group of the section will have as their speaker Anthony Turner of Taylor Instrument Co. His subject will be "Measurement of physical variables for electrical means."

The Nov. 20 meeting will feature ASQC Vice President Ervin E. Schiesel, Mattuatuck Mfg. Co., Waterbury, Conn. Mr. Schiesel will give us "Statistical cost control and analysis." Questions and discussion are always welcomed.

ST. LOUIS Prof. F. R. Kennedy associated with the College of Law at the University of Iowa in Iowa City will be the guest speaker for our Oct. 19 meeting. He will speak on "Legal uses and implications of statistical data."

SOUTH TEXAS "Utilization of punched cards in a large quality control program" will be the subject of E. W. Bailey of Union Carbide Nuclear Co. at the Nov. 14 meeting.

TOLEDO The October meeting of the section will include a plant trip through the Pure Oil Co. on Otter Creek Road in Toledo. The trip will be preceded by a dinner at the plant.



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WESTERN MASSACHUSETTS On Nov. 13 Warren Purcell of Rath & Strong will lecture the section at the Shearton-Kimball Hotel in Springfield on the "Pursuit of facts." Mr. Purcell will develop the various techniques for gathering facts and the use of these for better process control.

"AS YE SOW . . ."

CHICAGO Meetings of the advanced educational series, featuring explanations and case histories of modern statistical methods included in Dr. Youden's text, will be held on Oct. 23 and 30, and Nov. 6 and 13. The classroom will be at Chicago's Wahl-Henius Institute.

MILWAUKEE Jim Schaeffer, University of Wisconsin, Extension Div., is developing a course of educational sessions to be held in addition to our monthly meetings. They will be on the intermediate level.

RHODE ISLAND The section and the University of Rhode Island have recently completed plans for a co-sponsorship in a certificate program in quality control management. This program will require the completion of four 30-hour semester courses to be given at the University's Extension Division. The certificate in quality control management will be awarded at the successful completion of the two year course.

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The purpose of this program is to provide executives, supervisors, engineers and inspection personnel with knowledge for coordinating the quality maintenance and improvement efforts of the various groups in an industrial organization so they can produce their products at the most economical levels which allow for full customer satisfaction.

An outline of the four semester courses is: No. 1—principles of quality control; No. 2—statistical methods of the quality function; No. 3—advanced statistical analysis; No. 4—quality control administration. Publicity and other details are currently being planned. The first course is tentatively scheduled to start in October.

WESTERN MASSACHUSETTS Oct. 22 is the time for the start of the weekly series of five lectures on applications of "operation research." Each lecture will be given by a different speaker who will present a problem, develop techniques to be used in solution, and enumerate the benefits to be derived. The course will be given in conjunction with the University Extension, Massachusetts Department of Education.

THIRD ANNUAL STATISTICS SHOW NOVEMBER 29 The Baruch School of Business of the City College in cooperation with the New York Metropolitan Chapter of the American Statistical Association and the ASQC will hold its third annual statistics show at The City College (17 Lexington Ave., New York City) on Nov. 29 from 10 am to 10 pm.

The show will feature exhibits by statistical and research agencies, governmental statistical organizations and professional societies in the field, as well as manufacturers and distributors of statistical machines. The show will be open without charge to the general public as well as students and practitioners in the field.

THIRD CLEVELAND QC CONFERENCE OCTOBER 25 The Cleveland section will hold its third annual one-day conference at the Carter Hotel in Cleveland on Oct. 25. The conference will consist of 12 qualified speakers on various phases of SQC under the general headings of current techniques, theory and design and special applications. A special feature will be a vendor-vendee panel discussion covering the important area of customer-supplier relationships.

Chairman of the conference is Paul Kuckuck, The Weatherhead Co., 300 E. 131st St., Cleveland. Reservations may be made through the registration chairman, Dorsey E. Dean, Firestone Tire & Rubber Co., 1200 Firestone Parkway, Akron 17, Ohio. Price of entire conference, luncheon and banquet is $17.50.

"FOR MANY ARE CALLED, BUT FEW ARE . . ."

COLUMBUS The new section chairman of the section is Kenneth I. Brooks of the Ternstedt Div., GMC. Vice chairman is Robert Coffman, Timken Roller Bearing Co. These two changes were brought about due to the transfer of jobs by Ervin F. Taylor, 1956-57 chairman.

CORNING -ELMIRA Due to the resignation of Paul M. Tice as vice chairman of the section, the following changes have been made. Former Secretary Herman Albertine of Westinghouse-Horseheads will become vice chairman and replacing

A two-weeks course in industrial statistics was held at the University of Oklahoma, July 9-20, under the direction of R. L. Huntington, research professor of chemical engineering. Emphasis was placed on the application of statistics in the solution of refining and chemical processing problems, design of experiments, analysis of data. In view of the successful results of this first meeting to be held in the Southwest, plans are being made for a similar course next summer. The above photo shows the members of this first class in industrial statistics. Front row, (kneeling and seated) left to right; Abdul Khan, Bill Hartman, Gayle McElrath, Oscar Kempthorne, R. L. Huntington, John C. Brixey, Ed Aldredge, A. R. Stark, and Byron Brown. Back row, (standing) left to right; George Hanson, Charles Neff, Abdul Hakim, Paul Kline, Chien-tai Liu, C. C. Sprinkle, Khaleeq Ahmed, Mervin Rosenbaum, Earl Stewart, Keith Miller, Alfred Heyman, Fred Applegath, C. D. Wallace, Mrs. Edna Fay Johnson, George Kellen, S. V. Burks, Bill Browers, Gordon Warren, Muhammad Ayub, Capt. George King, Samuel Ford, C. A. Robertus, Joe Browning, Sanford Swasey, J. E. Powers, D. M. Strasser, and George Cummings.

him as secretary will be E. B. Godsey of the Corning Glass Works.

MILWAUKEE George Craycraft, former treasurer of the section is now treasurer pro-tempore by appointment of the section's executive committee. The treasurer, Clarence Dewus, who was elected last spring has been transferred to another position in his company which requires him to be out of the city unexpectedly.

TOLEDO The four elected officers of the section are Wm. W. Pounds, chairman; Hilton C. Fetting, vice chairman; David A. Hettel, secretary; and Ward Wright, treasurer.

DIVISIONS

Administrative Applications Division

The Administrative Applications Division will hold its first conference at the Congress Hotel in Chicago on Friday and Saturday, February 8 and 9. Eighteen speakers will cover the three major fields of Division interest—management, industrial engineering and clerical and accounting. Among those who have been invited to speak are D. E. Bein, A. O. Smith Corp., Milwaukee, Wis., "The use of automatic computing equipment and statistical methods in research and development;" J. C. Werner, Werner Textile Consultants, Atlanta, Ga., "Application of statistical methods to human relations and personnel testing;" C. L. Brisley, Wolverine Tube Div., Calumet S. Hecla Consolidated Copper Co., Detroit, Mich., "Work sampling;" Wilbur F. Hoehing, Westinghouse Electric Corp., Sharon, Pa., "Quantitative methods of production and inventory control;" Prof. Charles Holt, Carnegie Institute of Technology, Pittsburgh, Pa., "Controlling inventory and production in the face of uncertain sales;" J. Y. McClure, Convair, Ft. Worth, Texas, "Quality control as a tool of management;" Dr. Leonard W. Swanson, Arthur Andersen Co., Chicago, Ill., "Sampling in accounting;" Blair E. Olmstead, Prudential Life Insurance Co., Newark, N. J., "Clerical quality control applications;" Henry J. Jacobson, P. R. Mallory Co., Indianapolis, Ind., "Quality control for purchasing agents"; R. B. Sharble, Standard Register Co., Dayton, Ohio, "Statistical cost control"; Leon Gilford, U. S. Census Bureau, Washington, D. C., "Statistical quality control in clerical work;" Dorian Shainin, Rath and Strong, Boston, Mass., "Controlling the quality of management decisions."

At Friday's luncheon A. F. Jacobson, President of Northwestern Bell Telephone Co., will speak on "Establishing comparable performance indexes for different departments of our telephone companies," to be followed at an afternoon session by a presentation on "Technical problems in establishing comparable performance indexes," by Bob Newman, also of Northwestern Bell Telephone Co.

Aircraft Division

The District Councilors for the Aircraft Division for the 1956-57 season are: District 1—L. A. Seder, 267 Hawthorne St., Malden, Mass.; District 2—F. P. Grimes, Aircooled Motors, Inc., Syracuse, N. Y.; District 4—Henry M. Zurdeeg, Canadair, Ltd., Montreal, Quebec; District 5—T. G. Gregory, Thompson Products, Inc., Danville, Pa.; District 8—W. F. Morgan, North American Aviation, Columbus, Ohio; District 9—Jackson Hurt, Allison Div., GMC, Plant #5, Maywood, Ind.; District 10—K. V. Holm, Vinco Corp., Detroit, Mich.; District 13—G. G. Biggs, Cessna Aircraft, Wichita, Kans.; District 14—G. W. Howard, Convair Aircraft, Ft. Worth, Texas; District 16—D. R. Archibald, Convair Aircraft, San Diego, Calif.

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Electronics Division

The elected officers for the year were announced at the first annual meeting of the Electronics Division which was held in Montreal, Canada. They are: chairman—A. B. Mundel, Sonotone Corp., Elmsford, N. Y.; vice chairman—I. W. Schoeninger, Centralab, Milwaukee, Wis.; secretary—H. A. Schumer, International Resistance Co., Philadelphia, Pa.; treasurer—R. G. Fitzgibbons, Bendix Products Div., Mishawaka, Ind. Elected as district councilors were: district 2—G. Armour, G. E. Co.; district 3—O. C. Simms, Sperry Gyroscope; district 5—G. Beckhart, R. C. A.; district 11—W. Lieberman, Gudeman Co.; district 12—R. Carlson, Maico Co.; district 16—D. Voetglen, Hughes Aircraft.

In an effort to provide the membership with more information concerning the field of quality control, it was decided that copies of acceptance procedures of RETMA would be distributed to the membership, perhaps as an aid in selling the philosophy to our less sophisticated brethren.

The division has several other major activities planned for the coming year including co-sponsorship of the Third National Reliability Symposium to be held in Washington, D. C. on January 14, 1957.

The division has grown to approximately 550 members and welcomes any other interested parties. Additional information concerning the division's activities may be obtained by writing to the secretary at 401 N. Broad St., Philadelphia 8, Pa.

MEMBERSHIP CORNER

The South Bend-Mishawaka Section tells us of some of their methods in membership promotion which have certainly paid off. This section was the winner of the Tenth Anniversary Year Award of the National Membership Committee.

1. Procure from the Manufacturers Association or Chamber of Commerce of the communities in your area lists of all of their industries. Inquire of these industries their inspection or quality control director, personnel, supervisors, and others. Write or otherwise communicate with all of the above members or prospective members of ASQC inviting them to a meeting.
2. Your program is all important. The memberships of some sections have remained static because their programs have been of too advanced nature and not sufficiently educational to interest new untrained members—others have lost membership because of the disinteresting nature of programs to the more advanced members. PROGRAMS MUST RETAIN THE INTEREST OF MEMBERS ADVANCED IN QUALITY CONTROL AND AT THE SAME TIME NOT BE BEYOND THE COMPREHENSION OF THOSE WITH LIMITED EXPOSURE. The limitations of the treasury at first might seem to be discouraging to the acquirement of speakers. Very fortunately there are many individuals who are dedicated to this work and many of them are employed in industries which are generous in cooperating to allow time and expenses in spreading the good work. THE NATIONAL SOCIETY PROVIDES LISTS OF SPEAKERS, some of whom donate their services entirely gratis and others whose only renumeration is expenses.
3. There are no known magic formulae for promoting the growth of a section. This is accomplished through

the accumulative hard work and cooperative efforts of the officers, committeemen, and membership as a whole. There must be an unrelenting search for new membership material. Interest in this science must be stimulated, created, taught ,and practiced. One of the most effective potentials toward this end is the development of classes in statistical applications. These classes not only promote, stimulate, and create interest and knowledge, but provide a fine source for new members.

4. It is our practice to register all members and guests in attendance at meetings. GUESTS ARE THEN SENT LETTERS THANKING THEM FOR THEIR INTEREST, INVITING THEM TO ALL MEETINGS, AND ALSO INCLUDED IS A MEMBERSHIP APPLICATION.
5. All meetings should receive as extensive publicity as is possible by announcements or news items in the newspapers in all of the communities in the area. Attractive appealing announcements should be sent to members, former guests, any prospective members, and leaders of industry. PARTICIPATION OF AS MANY MEMBERS AS POSSIBLE SHOULD BE ENCOURAGED IN SECTION ACTIVITIES.

These fundamental practices, if consistently followed, are the backbone of solid membership growth because they retain existing members and attract new ones.

SIGNIFICANT DIFFERENCES

Ervin F. Taylor has taken a position with Westinghouse Electric Co., Atomic Energy Div., in Pittsburgh, Pa. Mr. Taylor was formerly with North American Aviation at Columbus and was the 1956-57 chairman of the Columbus section.

E. M. McIlwain, member of the Corning-Elmira section, former quality control manager of Pilot Plant #2, Corning Glass Works, has recently been promoted to the position of chief process and quality engineer of the Refractories Plant.

One of the newer members of the Harrisburg section, Oscar Fox, was recently promoted to manager of quality control of the York Div., Borg-Warner Corp.

The prolific writer of the Louisville section, Allan T. Thomas, has a second article in the September issue of the *Journal of Agricultural and Food Chemistry*. This is titled "A pilot plant study—the utilization of leucine by saccharomyces cerezisiae"—which to lay people is plain baker's yeast.

Dr. Josef Talacko, statistician at Marquette University and senior member of the Milwaukee section, has been promoted to associate professor of mathematics.

Glen S. Goodman, senior member of the St. Louis section, is now associated with the International Resistance Co. at Burlington, Iowa. Mr. Goodman was formerly with McQuay-Norris who are no longer in operation as the Government has put it on a stand-by basis.

George F. Lunger, Detroit section member, has resigned his position as senior analyst on the Ford Motor Co. QC staff to accept a position as mathematician in the advanced applications section of the Univac Div. of Sperry Rand Corp. located at St. Paul, Minn.

Joseph Palmieri, arrangement chairman of the New Haven section, has been put in charge of all quality control functions at the West Haven, Conn. plant of Armstrong Rubber Co.

C. T. (Tiny) Shewell, District 14 Councilor for the Chemical Division and recently elected District 14 Representative, has been promoted to senior research specialist in the research and development division of Humble Oil and Refining Co.'s Baytown Refinery. Mr. Shewell, South Texas section, has also been notified of his election to status of Fellow in the Society.

J. H. Moyer, Midwest Director and junior past chairman of the South Texas section, has recently been appointed statistical control and analysis supervisor of the Champion Paper and Fiber Co., Texas Div. Mr. Sanford Swasey was named assistant to the S. C. and A. supervisor. Both positions are newly created.

John Hinchen, last year's Western Massachusetts section chairman, has been picked by Monsanto Chemical Co. to fill a newly created position of superintendent of planning and control. Mr. Hinchen has been a supervisor of industrial statistics. He holds a BS degree, cum laude in physics, from St. Peters College. He has lectured widely, written papers on quality control, and given generously of his time to ASQC activities.

IBM Corp. has announced the appointment of William E. Andrus, Jr. to the position of manager of the Scientific Computation Laboratory. Mr. Andrus, senior member of the Binghamton section, was formerly an associate staff mathematician.

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Bibliography

JOSEPH MOVSHIN, *Editor*

Assisted by the Editorial Committee, St. Louis Section, ASQC

BIBLIOGRAPHICAL

SYMPOSIUM ON QUALITY CONTROL IN INDIA,
(American Ceramic Society Bulletin, v. 35, n. 4, Apr., 1956, p. 163)

Twenty-six papers on Quality Control in glass industry are listed. These were given on December 21, 22, 1955, by Indian, British, and American writers in Calcutta, India.

APPLICATION—
TEXTILE INDUSTRY

SURVEY OF CONTROL CHART APPLICATIONS IN TEXTILE PROCESSING, by Norbert L. Enrick, (Institute of Textile Technology, Charlottesville, Virginia)
(Textile Research Journal, v. XXVI, n. 4, Apr., 1956, p. 313-316)

In reviewing the application of control charts in textile processing, four control charts seem to be most widely used. These are: (1) control chart for sample averages, (2) control chart for sample ranges, (3) control chart for defects per unit, and (4) control chart for percent defective.

An analysis of applications in more than fifty mills indicates that these charts can be successfully applied to the following area: (1) raw materials testing, (2) stock weight and variation, (3) linear uniformity of stock, (4) running conditions of stock, (5) reworkable and nonreworkable waste, (6) processing tests, and (7) end-product evaluation.

General benefits and advantages of the application of control chart methods are discussed.

TESTS FOR BETTER SPINNING, by Norbert L. Enrick, (Institute of Textile Technology, Charlottesville, Virginia)
(Modern Textiles Magazine, June, 1956, p. 63-68)

This fourth article in the series of mill test procedures in quality control continues the detailed discussions of test procedures, frequency of testing, forms and recording test results and standards. This particular article is devoted to spinning quality control.

MORE TESTS FOR BETTER SPINNING, by Norbert L. Enrick, (Institute of Textile Technology, Charlottesville, Virginia)
(Modern Textiles Magazine, Aug., 1956, p. 37-42)

Selected references in the Bibliography of *Industrial Quality Control* are obtained from the following sources:

The International Statistical Institute, *International Journal of Abstracts on Statistical Methods in Industry.*

This article continues the spinning tests described in the fourth article of the series. More details on the various tests are given again with detailed procedures, standards and evaluation methods.

APPLICATION—
MISCELLANEOUS

HOW TO USE STATISTICAL QUALITY CONTROL FOR MATERIALS SELECTION, by D. Peckner
(Materials and Methods, v. 43, n. 4, Apr., 1956, p. 120-122)

Statistical quality control simplified and applied by use of arithmetic and probability paper. Specification limits are set up, material performance is checked over a period of time, and supplier's claims concerning his product can be accurately checked.

ENGINEERING AND EXPERIMENTS

STATISTICAL TECHNIQUES FOR REDUCING EXPERIMENT TIME IN RELIABILITY STUDIES, by M. Sobel
(Bell System Technical Journal, v. 35, n. 1, Jan., 1956, p. 179-202)

Advantages and disadvantages of three statistical techniques for reducing average duration of life tests are discussed. These techniques are: increasing initial number of units on test, using replacement technique, and using sequential procedure.

MANUFACTURING COSTS AS RELATED TO PRODUCT DESIGN, by Lad J. Bayer, Chief Ind. Eng. (Warner & Swasey Company, Cleveland, Ohio)
(Tooling and Production, v. XXII, n. 5, Aug., 1956, p. 73-77)

This article discusses the relationship between various aspects of design tolerances and the cost of a product. Charts showing the relationship between various design factors and cost are given. Included are such factors as surface finish, depth of drilled holes, tolerances on internal grinding, tolerances verses centerless grinding. In general, better finishes and more accurate dimensions result in higher costs.

MISCELLANEOUS

COSTS HIGH? TRY THESE FOR SIZE!
(Production, v. 38, n. 2, Aug., 1956, p. 104-107)

This section of a cost control series contains several short case histories of cost control in an inspection operation. These include the use of an electronic gaging device and selective fitting parts; a taper gage device and some comments on savings through sampling techniques which cut inspection time without rejection

1958 BOSTON HOST GROUP

Wade R. Weaver, chairman of the general convention committee, announces that the group which will assume the responsibilities for hosting the 1958 convention in Boston has been formulated. Composition of the Boston Host Group is as follows:

Chairman: Warren J. Grosjean, General Electric Co., Ashland, Mass.
Arrangements: Martin W. Rogers, National Co., Malden, Mass.
Publicity: Harry B. Duane, General Electric Co., West Lynn, Mass.
Exhibits: Francis B. Kilduff, General Electric Co., Ashland, Mass.
Reception: Harold J. Davis, Raytheon Corp., Newton, Mass.
Registration: Dorothea R. Looney, The Polaroid Co., Cambridge, Mass.
Program: Forest G. Fales, Sylvania Products Corp., Salem, Mass.
Book Booth: Arthur A. Costello, Keystone Camera Co., Boston, Mass.
Advisory: Leonard A. Seder, Consultant, Malden, Mass.
Secretary: Frances E. Hermann, Arthur D. Little Co., Cambridge, Mass.

Several meetings have already been held and active planning is already under way. The combined facilities of the Statler and Sheraton Plaza Hotels will be required to handle our constantly growing convention activities. The dates are Monday, Tuesday, and Wednesday, May 26-27-28, 1958.

risk. A leakage test for compressor assemblies is also described. YOUR DIALS WILL READ JUST RIGHT, by Federal Products Corporation, Providence, R. I. (Factory Management and Maintenance, v. 114, n. 8, Aug., 1956, p. 98-99)

This short article gives twenty rules for the maintenance and use of dial indicators. The ten "do's" and ten "don't's" are presented as aids to maintaining dial indicator accuracy and longer life.

SAMPLING PLANS AND RELATED TOPICS

SUPPLYING SUPERVISORS WITH FACTS HOT OFF THE PRODUCTION LINE, by Ernest W. Karlin, Statistical Quality Control Department, (Bendix Aviation Corporation, Eatontown, New Jersey)

(Factory Management and Maintenance, v. 114, n. 8, Aug., 1956, p. 124-125)

A defects control chart using a number of defects acceptance table developed by General Electric is outlined. For each of numerous defects reported daily, the acceptance figure in $\bar{p}$ is presented. By reference to a number defective table for the quantity involved and the $\bar{p}$ standard, the appropriate daily sections are color coded for in control, out of control—high, or out of control—low.

BOOK REVIEWS

W. D. Baten, Editor

STATISTICS: A NEW APPROACH, by W. Allen Wallis and Harry V. Roberts; XIII plus 646; The Free Press, Glencoe, Illinois, 1956; price $6.00. Reviewed by W. D. Baten.

The first part, *The Nature of Statistics*, contains chapters on the nature of statistics, uses of statistics, misuses of statistics, basic ideas and observation and measurement, in which the authors skillfully cause the reader to thoughtfully ponder on effective ways of approaching solutions to important problems, the need of securing pertinent data and what conclusions should be made. The student, at this stage in his statistical development, may not have adequate statistical tools and sufficient knowledge for solving the problems suggested, yet reading this part will acquaint him with several statistical investigations which will bring him face to face with many worthwhile ideas about some of the facets of statistics.

The chapter of misuses of statistics calls the reader's attention to pitfalls which may arise if careful plans and designs are not thought out in the beginning. Several examples are given of faulty conclusions brought about because of inadequate data. There appears to be an attempt to force the reader to think more clearly about proper solutions. Many will read this first part more than once. This introductory material will create lively class discussions and may motivate more interest in statistics.

Part II, *Statistical Description*, consists of chapters on the art of organizing data, averages, variability and association in which many basic terms are defined such as, frequency distributions, measures of central tendency, measures of dispersion, and an index of order association. No derivations of formulas or proofs of theorems are presented here or elsewhere in the book. The authors expect teachers that use their book to stress important ideas, develop formulas and prove theorems pertaining to the statistics included in this part. The reader is encouraged to understand statistical philosophy rather than devote much time to computational exercises, however, each term is illustrated with a numerical example. Each chapter in the book ends with a "Do it Yourself" section in which exercises and problems are given for the stu-

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dent; many of them call for thoughtful approaches.

Part III, *Statistical Inference*, includes chapters on randomness and probability, sampling distributions and the normal distribution, further test procedures, statistical tests and decision procedures and estimation in which are well explained ideas concerning statistical inference, random samples, probability, the nature of sampling distribution, of proportions, decision procedure, operating characteristic curve, hypotheses, errors of the first and second type, one sided and two sided alternatives, significant tests for means and for proportions, Student's t, confidence interval estimates for means, and proportions. This part is the heart of the book and contains many fundamental ideas which are presented by charts, illustrations and the uses of probabilities. Here the reader is shown clearly, many of the real objects of statistics and what one may conclude about universes from which random samples are drawn. The authors have shown basic concepts pertaining to risks so that the student will appreciate what may be derived from sound statistics. The normal distribution is used for most tests of significance among averages and among proportions. The chi-square test is mentioned but not recommended for use. The reader is not encouraged to use Student's t test because the t-distribution does not differ very much from the normal distribution.

Part IV, *Special Topics*, consists of chapters on design of investigations, statistical quality control, relationship between variables, time series and shortcuts, which contain material about analysis of variances, sampling techniques, acceptance inspection, control charts, sequential sampling, correlation, regression, moving averages, seasonal variation, and how to use binomial probability paper.

There is very little material pertaining to designs of experiments. The chapter on quality control is not adequate for presenting many of the fundamentals in this field. The topics on correlation and time series will enable the reader to comprehend many underlying principles and will introduce him to much of the philosophies of these two fields of statistics.

The last chapter gives short cuts for securing rough estimates of confidence intervals, comparing averages, testing matched samples, determining whether two variables are correlated. All of these tests are based upon quantities that are normally distributed and the use of the normal curve table. Binomial probability paper is well presented with several illustrations on how to use it. It is used for the chi-square test, for the F-test, confidence intervals for proportions and testing two proportions. The reader will find this chapter to contain material that is not presented in text books on statistics.

The appendix contains a table of square roots of numbers for N and 10N when N = numbers from 1 to 1000, and a table of 10,000 random numbers.

Statisticians will want this new approach to statistics in their library.

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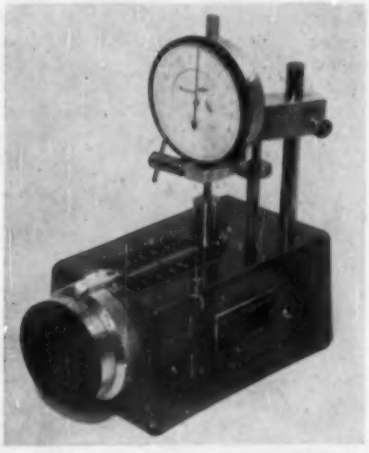
What's New?

ROY A. WYLIE, *Editor*

When inquiring about "What's New?" items, please mention INDUSTRIAL QUALITY CONTROL

P. K. Neuses, Inc., West Euclid and Dwyer Streets, Arlington Heights, Ill. has introduced a new spring tension gage for accurately determining settings or for checking the tensions of relay or other springs. The unit consists of a nickle silver frame on which are assembled an indicating spring, a folding handle and an adjustable tension attachment. The folding handle when closed serves as a protector for the indicating spring. The adjustable tension attachment provides for setting the indicating spring at an initial tension. Tensions are registered in grams. The scale is calibrated on front and back so that the gauge can be used for indicating left to right or right to left. The size is 4½ x 1½ inches. Four models are available ranging from 10 grams either side of center zero in 1 gram steps to 150 grams from zero at side of 5 gram steps.

★ ★ ★



Custom Scientific Instruments, Inc., Kearney, N. J. have developed a dial indicator calibrator for checking and calibrating the accuracy of dial indicators. In operation, a plunger is raised by a hardened wedge which is driven by a precision screw. The screw is operated by a vernier arrangement with the outer dial graduated in incruments of 0.000025 inches. The inner dial, for rapid travel, is knurled and drives the screw through a set of planetary gears. Range of the dial indicator calibrator is zero to ½ inch travel for CW or CCW indicators. The housing is a stress relieved casting and all internal parts are hardened steel. An adjustable split take-up nut on the screw is used to compensate for wear.

★ ★ ★

Viking Instruments, Inc., East Haddam, Conn. have developed the Viking Void Detector, an electrical instrument designed for the detection of minute or large holes in any material which is electrically non-conducting. The standard model tests material such as paper, plastic and rubber up to 0.025 inches thick and records holes of 1/64 inches in diameter and larger. The detecting and recording system includes the use of a one, two or three position indicator unit connected electrically to feeler brushes. The feeler brushes are attached to the roll, plate or bar which is processing the dielectrical material. Whenever a void in the material passes between the feeler brush and the grounded roll, plate or bar, a low voltage pulse is transmitted to the indicator unit where it is measured and recorded. A sensitivity adjustment permits the differentiation between hole sizes to be detected. The two and three position instruments not only record all holes and count them, but indicate the sections in which the holes appear. Each device is equipped with switches designed to permit testing of each indicating position prior to and during operation. Counter units are electrically actuated and manually reset. The visual signal is incorporated in the unit and provisions are made for the connection of audible alarms and 24-hour recording equipment.

★ ★ ★

The Betameter, an instrument employing bata radiation for accurate measurement of mass per unit area of material is announced by **Isotope Products, Inc.**, 1700 Niagara St., Buffalo 7, N. Y. It is used to measure and control sheet thickness, basis weight, coatings, etc. in continuous manufacturing processes. It is particularly adapted to measurements which cannot be made with conventional equipment because the instrument does not physically contact the measured materials. All materials absorb beta rays—the greater the mass, the greater is the absorption and the fewer the number of rays which pass through the material. By measuring the rays which do get through, an extremely accurate measurement of mass per unit area is obtained. In the measurement of sheets with the Betameter, a sealed "source" emitting beta rays is mounted on one side of the sheet, a radiation detector on the opposite side. The current generated in the detector is correlated directly with the sheet mass and so with sheet thickness. Scales can be set up to read in any desired units. Principle feature of the Betameter is its "null balanced operation" by which the small signal from the detector is balanced against an identical signal from a second source and detector inside the instrument. The difference is amplified to record the amount that the sheet is "off weight" from the desired standard. Null balance operation insures greatest stability and accuracy and also provides a means of continuous standardization. The decay of the radioactive source, the effects of air pressure and temperature, all are cancelled out, continuously and automatically with no need for standardization interruptions. It can be used in the manufacture of paper and board, rubber, plastics, metal foil and sheets, linoleum, glass fibre insulation and other materials.

★ ★ ★

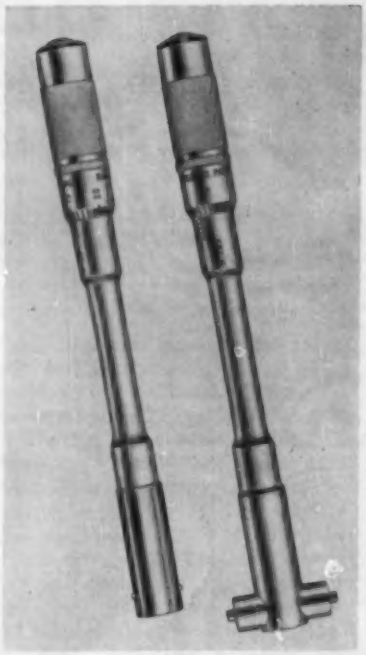
Model 424 D.C. Hypot produced by **Associated Research, Inc.**, 3758 W. Belmont Ave., Chicago 18, Ill. has been redesigned for increased efficiency and range of application. The Hypot features continuously variable output voltage from zero to 5,000 volts D.C. with this voltage now obtained through selenium rectifiers, thus eliminating tubes and filament

transformers. For measuring leakage current, ranges of zero to 5-10-50-100 microamperes are provided on a 4½ inch microammeter automatically protected against overload and accurate to 3 percent. Output terminates in two 5 foot long voltage leads with the "hot" lead equipped with a retractable tip prod. Leads are now brought out the front of the case for convenience and are plug-in type so that they can be disconnected when not in use. Controls include continuously variable auto-transformer to vary output voltage, "high voltage on" switch with pilot light and "filament on" switch with pilot light. The case is rack and panel type 22 inches wide by 14¾ inches deep by 12⅝ inches high, equipped with carrying handles and lid interlock. It can be supplied with chassis only for panel mounting. Net weight of the complete unit is 25 lbs.

★ ★ ★

A new hole locating and tubing micrometer has been introduced by the **Lufkin Rule Co.**, Saginaw, Mich. This new micrometer has an 0.089 inch anvil, small enough to enter a 3/32 inch I.D. hole or slot. The anvil is held with a set screw and can be easily and quickly replaced in case of wear or breakage. The micrometer has a non-glaring Chrome Clad finish on the thimble and hub, and a black enameled, heavy duty ribbed, half frame. It has a range of zero to 1 inch by 1000ths and is furnished with either a plain thimble or a ratchet cap. Price is $19.00 for the plain thimble micrometer and $20.00 for the ratchet cap.

★ ★ ★



A new line of small diameter Inside Micrometers has been announced by **Rimate Gage Co.**, 21 W. Dayton St. Pasadena, Calif. The new P and PX series cover a range of measurements beginning at 0.310 inches and continuing through 1.250 inches. P series Inside Micrometers have gaging tips which are rectangular in cross-section, permitting the construction of a rugged mechanism for checking very thin grooves and recesses. The rectangular design also provides immediate centralization to a positive line contact stop. When checking ordinary bores, the fact that no-rocking is required permits the use of these micrometers by unskilled personnel. P series micrometers have tip widths of 1/16, 3/32, and ⅛ inches. PX series micrometers have tip widths of 0.015, 0.025, and 0.035 inches. Additional information is available from the manufacturer.

★ ★ ★

Testing the ductility of very thin metals is the function of a new cup tester developed by **Steel City Testing Machines, Inc.**, 8817 Lyndon Ave., Detroit 38, Mich. The new machine can be used for testing many different types of metals including copper, brass, aluminum, tin plate, stainless steel, and carbon steel. Thickness ranges from 0.003 to 0.062 inches are accommodated. The cup tester is a bench-mounted, hydraulically operated unit with power supplied by a 1/6 H.P. motor mounted on the rear of the base. Two valves on the front of the base provide infinite control of the testing operation. Depth of cup is shown by a dial indicator which is fitted with a friction brake so that maximum deflection readings are retained until released by the operator. Maximum load at time of yield is shown by a

red hand on the load gauge. The ball penetrator is standard ⅞ inch diameter and the die supplied with the machine is 1 inch diameter. While the minimum width for use with a ⅞ inch penetrator is recommended to be 2 inches, narrower strip can be tested by using special small-diameter penetrators. Such special penetrators, with matching dies and clamping plates, are available with Model D at slight extra cost. Overall size of the new tester is 11½×21×25 inches high. Net weight is less than 200 lbs.

★ ★ ★

Announcement of New DoALL Exhibit

The DoALL Company is preparing a new exhibit which should be of particular interest to the members of our Society. It is as dramatic as "Civilization Through Tools" was and is called "THE STORY OF MEASUREMENT." This show tells the history of measurement with cinerama-type slides portraying note-worthy scenes and events in the progress of measurement. These scenes are explained in an accompanying commentary.

The presentation is supported by five panels of historical items and models of measuring instruments such as an exact replica of a "cubit stick," the standard of linear measure in Egypt thousands of years ago. This is just one item in a series that explains the development of linear standards up to present day English and metric systems. The display also contains such rare items as Major Hoke's original master set of gage blocks and one of the earliest micrometers.

"THE STORY OF MEASUREMENT" explains "interferometry," the method of utilizing light, that immutable standard of length, in establishing the accuracy of present day reference standards—gage blocks. The relationship of modern mass production precepts to precision measurement and the latest developments in the progress of this science are also covered.

The physical specifications of the exhibit are as follows. The screen measures approximately 17 feet wide and 12 feet high. Total length required by the five panels is approximately 29 feet. Height of the panels on their easels is 8 feet. The area accommodating the panels should be 10 feet deep to allow for the depth of easel and for walk-by space for viewers.

Further information regarding this new exhibit may be obtained from Mr. C. H. Rosene, DoALL Company, 254 North Laurel Avenue, Des Plaines, Illinois.

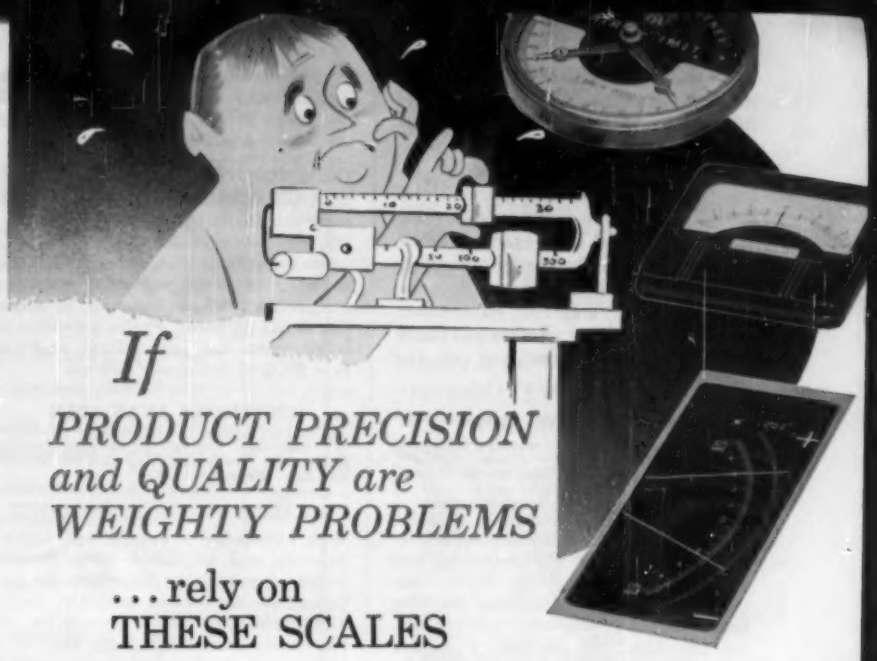
Two new profile projectors and comparators have been introduced by **William J. Hacker & Co., Inc.**, 82 Beaver St., New York 5, N. Y. These instruments are equipped to provide simple, fast and accurate optical inspection of machined parts, tools, gears, forms, lamp filaments and other objects. Parts to be inspected are placed on a horizontal stage equipped with micrometer adjustment in two directions. Coarse and fine focusing is accomplished by means of vertical movement of the stage. The smaller of these projectors has a viewing screen measuring 8×8 inches while the larger model has a viewing screen 12½×11 inches approximately. Magnifications from 10 to 50 times are available. Both models are readily portable and can be placed on any available table.

★ ★ ★

NEW LITERATURE

A new illustrated catalog covering Carbon and Sulfur Determinators manufactured by Harry W. Dietert Company, 9330 Roselawn, Detroit 4, Mich. is available on request. The Dietert two-minute carbon determinator is used for quantitative determination of carbon in metals, petroleum catalysts, organic chemicals and other materials. The Dietert three-minute Sulfur Determinator renders an accurate measurement of sulfur content in metals, minerals, coal and coke, rubber, petroleum products and other organic and inorganic materials.

A new line of Narda Standard Reflections specifically designed for calibrating slotted line impedance meters and standardizing reflectometers in the frequency range of 2600 to 18000 mc. are described in a data sheet just published by the Narda Corp., 160 Herricks Road, Mineola, L. I., N. Y.



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MACHINE TOOLS • GAGES • CUTTING TOOLS

A new Technical Manual describing the complete line of electrical indicating instruments and test equipment of Simpson Electric Co., 5200 W. Kinzie St., Chicago 44, Ill. has just been issued. Technical and design features of the various meter movements used in Simpson Electric meters are described and illustrated. Also contained is information on ranges, scale lengths, calibration, pointers, terminals, deflection characteristics, and sensitivity of the various meters.

POSITIONS WANTED

Address all replies to box number references to: American Society for Quality Control, Room 6197 Plankinton Bldg., 161 W. Wisconsin Ave., Milwaukee, Wis.

Have six years' experience in organizing and direction quality control activities. This includes the institution and administration of statistical quality control procedures and sampling plans on both finished product and manufacturing processes; the writing of quality control reports to top management; the design and analysis of experiments; representing my company to both customers and suppliers on all matters relative to quality problems; the writing and maintenance of a Manual of Quality Control Procedures and Specifications. Hold an advanced degree in SQC. Desire to move to progressive company as Manager or Assistant to Manager of Quality Control Department. Will relocate. Minimum salary required $8500 per year. Please reply to Box 13D1 at the above address.

DIRECTOR OR ASSISTANT DIRECTOR OF QUALITY CONTROL. Presently employed in a base metals industry, wishes to relocate. Age 44. Thirteen years experience includes application of statistics to plant processes, statistical quality control, and teaching of statistics at college level. Prefer suburban or small town location. Please reply to Box 13D2 at the above address.

POSITIONS AVAILABLE

Address all replies to box number references to: American Society for Quality Control, Room 6197 Plankinton Bldg., 161 W. Wisconsin Ave., Milwaukee, Wis.

QUALITY CONTROL ENGINEER

With knowledge of gage design, trouble shooting and inspection methods used in mass production. Experience in statistical quality control desirable. Salary $7,000 to $8,000. Ronson Corp. of Pa., 250 Harris St., East Stroudsburg, Pa.

Paper manufacturer with multi-plan operation has opening for recent engineering graduate in its staff quality control organization. It is desirable that this man have quality control or statistical training. More important, however, is that this man be a self-starter with initiative and ability to work with others. Location: Western Massachusetts. Please reply to Personnel Dept., Peter J. Schweitzer, Inc., Lee, Mass.

QUALITY CONTROL ENGINEER

Outstanding opportunity with leading San Francisco Bay Area electronics manufacturer in expanding quality control program. Engineering degree plus minimum of 3 years manufacturing experience required. Knowledge of statistical theory desirable. Please forward complete resumé. All replies held confidential. Please reply to Box 13R1 at the above address.

QUALITY CONTROL ANALYST

Permanent position on the Staff of the Director of the Quality Control Division of an established company in the New York City metropolitan area engaged in the engineering development and manufacture of complex electronic and mechanical control and computing systems. To assist in designs of experiments, analysis of data for statistical validity, quality level surveillance, etc.

A minimum of 2 years statistical quality control experience plus a major in mathematical statistics or its equivalent. Please send complete resume including salary requirements to Box 13R2 at the above address.

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Whether you have actual experience in Quality Control or not, if you are a qualified Engineer with the proper background to handle the job descriptions listed below, you can move into a top-paying permanent position with a major company!

General Electric's Aircraft Gas Turbine Division has immediate openings for Quality Control Engineers to work with our Research and Development Engineers, coordinating Design with inspectability, costs of tooling, inspection manpower requirements, and variables.

We also have openings for men in Advanced Quality Control Planning. These men will be assigned to Engineering Units as liaison between Engineering and Inspection Planning, and will designate and establish quality control requirements and costs for advanced work.

Experience necessary in machine construction and sheet metal fabrication; statistical quality control; and process and manpower variables in inspection.

Write, giving resume of your experience and qualifications. All inquiries strictly confidential.

ADDRESS: Mark Peters, Dept. QC,
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QUALITY CONTROL ENGINEER

A fully integrated quality control program is being planned for a new sanitary ware ceramic plant being built at Plainfield, Conn. This man will plan all inspection procedures, tests and experiments for defect prevention, quality assurance procedures, the application of statistical tests, and the planning of executive reports on quality. Preliminary training will be given at our plant in New Orleans, Louisiana.

Applicants must have had engineering training or equivalent experience in the field of modern industrial quality control. Kindly furnish resume of personal data and experience, including snapshot if available. Address replies to Personnel Administrator, American-Standard, P. O. Box 149, Danielson, Conn.

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A new fully integrated quality control program is being set up at Unit Plant which is manufacturing chrome plated brass plumbing fittings. Under the direction of the Quality Control Engineering Supervision these Engineers will plan all inspection procedures, tests and experiments for defect prevention, quality assurance procedures (audit and check inspection), the application of statistical tests, and the planning of executive reports on quality. Applicants must have had engineering training or equivalent experience in the field of modern industrial quality control. Kindly furnish resume of personal data and experience, including snapshot if available. Address replies to Personnel Administrator, American-Standard, 1541 South Seventh Street, Louisville 8, Kentucky.

REPORT OF EXAMINING COMMITTEE

The Examining Committee has just announced the election of the following members of the Society to the grade of FELLOW:

Name	Section
Marjorie M. Baskerville	Hamilton
Allin P. Deacon	Toronto
Norbert L. Enrick	Richmond
Charles T. Shewell	South Texas

The officers of the Society wish to congratulate these members for achieving this distinction.

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TEST FACILITIES ENGINEER

To analyze, plan and review design of quality control test equipment and test methods to comply with advanced electronic and electromechanical specifications.

These positions require an M. E. or E. E. degree with a mathematics or engineering background, and actual shop experience in the application of statistical techniques to electronics manufacturing operations.

The ability to design and follow through on statistical quality control procedures is essential.

These are responsible positions which will provide you with opportunity for professional advancement.

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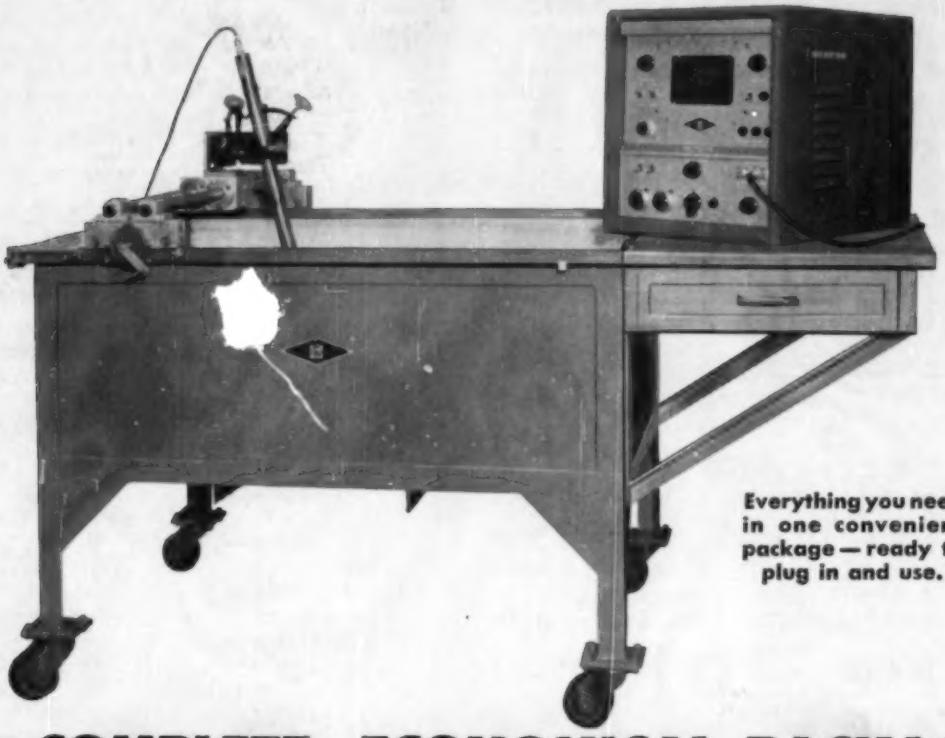

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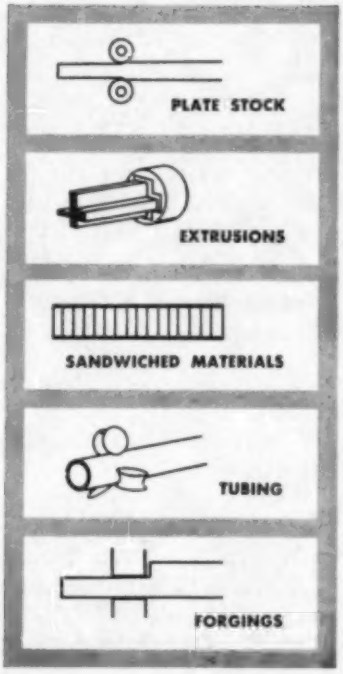

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